

**PROCEEDINGS OF THE 2003
NATIONAL OILHEAT RESEARCH ALLIANCE
TECHNOLOGY SYMPOSIUM**

**Held at the
2003 New England Fuel Institute Convention &
30th North American Heating and Energy Exposition
Hynes Convention Center, Prudential Center
Boston, Massachusetts
June 9-10, 2003**

**Editor
Roger J. McDonald**

June 2003

Sponsored by

**Distributed Energy and Electricity Reliability Program
Office of Energy Efficiency and Renewable Energy
United States Department of Energy**

New England Fuel Institute

National Oilheat Research Alliance

Petroleum Marketers Association of America

**Energy Resources Division
Energy Sciences and Technology Department
Brookhaven National Laboratory
Brookhaven Science Associates
Upton, New York 11973-5000**

**Under Contract No. DE-AC02-98CH10886 with the
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ACKNOWLEDGMENTS

The 2003 National Oilheat Research Alliance Technology Symposium required the dedicated effort of many people to make it successful. The editor of this report would like first to thank the authors for their efforts and splendid cooperation in submitting papers promptly. The BNL staff also wishes to recognize the contributions to our work by our U.S. DOE program manager, Ronald Fiskum, and thank him for his leadership. The editor also greatly acknowledges the hard work and effort required by the entire BNL program staff to make this meeting a success. Most of all the staff at BNL wish to thank all of our 2003 National Oilheat Research Alliance Technology Symposium sponsors and participants for their active participation.

I. INTRODUCTION

This meeting is the sixteenth oilheat industry technology meeting held since 1984 and the third since the National Oilheat Research Alliance (NORA) was formed. This year's symposium is a very important part of the effort in technology transfer, which is supported by the Oilheat Research Fuel Flexibility Program under the United States Department of Energy, Distributed Energy and Electricity Reliability Program (DEER). The foremost reason for the conference is to provide a platform for the exchange of information and perspectives among international researchers, engineers, manufacturers, service technicians, and marketers of oil-fired space-conditioning equipment. The conference provides a conduit by which information and ideas can be exchanged to examine present technologies, as well as helping to develop the future course for oil heating advancement. These conferences also serve as a stage for unifying government representatives, researchers, fuel oil marketers, and other members of the oil-heat industry in addressing technology advancements in this important energy use sector. The specific objectives of the conference are to:

- o Identify and evaluate the current state-of-the-art and recommend new initiatives for higher efficiency, a cleaner environment, and to satisfy consumer needs cost-effectively, reliably, and safely;
- o Foster cooperative interactions among federal and industrial representatives for the common goal of sustained economic growth and energy security via energy conservation.

The 2003 National Oilheat Research Alliance Technology Symposium is sponsored by the Distributed Energy and Electricity Reliability Program (DEER) within the Office of Energy Efficiency and Renewable Energy (EERE) at the United States Department of Energy (DOE), the National Oilheat Research Alliance (NORA), the New England Fuel Institute (NEFI), Brookhaven National Laboratory (BNL) and the Petroleum Marketers Association of America (PMAA). BNL is proud to acknowledge all of our sponsors, with their help and support this has correctly become an oilheat industry meeting. It is quite gratifying to see an industry come together to help support an activity like the technology symposium, for the benefit of the industry as a whole.

Introductory remarks will be provided by Doug Woosnam, Chairman of the NORA Research and Development Committee who will welcome the assembly on behalf of our sponsors. He will emphasize the continued commitment by NORA, DOE and BNL to advancing oil heat technology and effecting technology transfer to the private sector.

Nine technical presentations will be made during the two-day program, all related to oil-heat technology and equipment, these will cover a range of research, developmental, and demonstration activities being conducted within the United States and Europe, including:

- **NO_x – How Low is Achievable with Oilheating Combustion Systems)**
- **Babington Airtronic Burner, Residential Heating / Hot Water Field Test**
- **Effect of Water Emulsion Fuels on NO_x Formation in Oil Burners**
- **Micro-CHP [Cooling Heating and Power Generation] – The Next Level of Efficiency**
- **National Oilheat Research Alliance Fuel Performance Research Update**
- **Benefits and Advantages of Marketing Low Sulfur Heating Oil Including Results from a New York State Low Sulfur Market Demonstration**
- **The Green Fuel Option for the Oilheat Industry – Biofuel Research**
- **Laboratory Investigations on the Cold Temperature Combustion and Emission Considerations for North America**
- **Combustion Testing of a Bio-diesel Fuel Oil Blends in Residential Oil Burning Equipment**

Forum/Workshop

The second day of the symposium will include the last three papers as listed above, all dealing with biofuel technology and how it is impacting the oilheat industry. These papers will be introduced by Raymond Albrecht of the New York State Energy Research and Development Authority. Immediately follow the last paper, Mr. Albrecht will preside as the moderator of an open forum, a workshop session, that will deal with the topic of Biofuel Development for the Oilheat Industry.

Adjournment

Following the final group of technical presentations the formal portion of the symposium will be concluded with brief closing remarks by Roger McDonald, editor, symposium organizer and co-principal investigator, along with Thomas A. Butcher, Ph.D., for the BNL Oilheat Research Program.

II. Technical Presentations

Paper No. 01-03

NO_x – How Low is Achievable with Oilheating Combustion Systems?

Thomas A. Butcher, Ph.D., C. R. Krishna, Ph.D., Yusuf Celebi, and George Wei
Brookhaven National Laboratory

Building 526
12 North Sixth St.
Upton, NY 11973-5000
Phone: 631-344-7916
Fax: 631-341-2359
E-mail: butcher@bnl.gov
Internet: www.bnl.gov

and

Bola Kamath, Ph.D.
Heat Wise, Inc.
PO Box 662
Ridge, NY 11961-0662
Phone: 631-345-0447
FAX: 631-345-0451
E-mail: BKamath106@aol.com
Internet: www.heatwise.com

NO_x – How Low is Achievable with Oilheating Combustion Systems?
Thomas Butcher, Ph.D., C.R. Krishna, Ph.D., Yusuf Celebi, and George Wei
Brookhaven National Laboratory
and
Bola Kamath, Ph.D.
Heat Wise, Inc.

Abstract

In the recently completed Oilheat Industry Roadmap – Towards a Sustainable Energy Future, nitrogen oxide emissions (NO_x) were identified as an issue of concern in the competition between oil and other fuels. Research leading to low NO_x emissions was identified as one of the high priorities for future oilheat research. This year Brookhaven National Laboratory (BNL) has been exploring the technical feasibility of achieving NO_x emission under 10 ppm, a factor of 10 lower than current, yellow flame oil burners. Main technical routes to achieving this goal include ultra-low nitrogen content fuel, recirculating burners with special provision for startup, and vaporizing systems with porous media radiant burners. Technical issues and results of work at BNL are discussed. The goal has been achieved in laboratory systems. The experimental burner concepts are described in terms of the recent experience gained in the laboratory and how this might translate to practical burner designs. The next steps in developing these technologies will also be discussed.

Introduction

Nitrogen oxides (NO_x) includes both NO and NO₂ and are a pollutant emissions from all combustion sources. NO_x is a concern nationally, mainly because it combines with hydrocarbons in the atmosphere and, under the influence of sunlight, forms ozone – a strong health concern. The East Coast has, on average, high levels of ozone and so there is a particular emphasis on controlling NO_x emissions. Up to the present time the Eastern States have not imposed NO_x emission limits on small boilers and furnaces. It can be argued that the emissions from these sources are only a small fraction of the contributions from other sources and also, ozone is mostly a summer problem, not impacted directly by winter fuel use for heating. In some other parts of the U.S. – notably the Los Angeles region of California and the State of Texas, ozone concerns are even more severe and emission regulations which affect small boilers and furnaces have been put in place. In many parts of Europe, NO_x emission limits have been placed on small sources for many years and low-NO_x burners are common on the market place.

Gas-fired boilers are currently available with reported NO_x emissions under 10 ppm and, even where fuel selection is not driven by NO_x regulations, the lack of oil-fired options in this range supports arguments about the relative cleanliness of oil. Considering this, the region-specific regulations, the trends in Europe, and recognition that the future may bring NO_x regulations in more U.S. regions, there is a growing consensus that the oilheat industry should be proactive in developing U.S. options for low NO_x appliances.

In 2002, the U.S. Department of Energy and many other organizations collaborated to prepare a roadmap for the future of oilheat development [1]. One goal set during that process was the introduction of clean oil burners with emissions under 20 ppm, based on a nitrogen-free fuel. In

the current R&D program at BNL a goal has been set of establishing the technical feasibility of achieving emissions even lower – under 10 ppm.

This paper provides a brief summary of NO_x emissions with burners which are currently available on the market and describes the approaches being explored in the BNL program and the results-to-date.

Emission Levels for Current Burners

All burners currently on the market in the U.S. are of the retention head, yellow flame type. In prior work, NO_x emissions from these burners have been discussed [2,3]. During the 2002 NORA Technology Symposium several papers presented new data on NO_x emissions from conventional and advanced systems [4,5,6].

With conventional yellow flame systems the NO_x emissions depend upon the firing rate and the combustion chamber. Higher firing rates and increased refractory lining in the combustion chamber (hotter chamber) tend to produce higher flame temperatures and higher NO_x. Current U.S. systems range from roughly 75 ppm to 180 ppm. Arguably, 110 ppm is about the average for oil combustion with yellow flame burners.

A great deal of effort (largely in Europe) has been put into the development of low-NO_x residential oil burners based on high rates of recirculation of combustion products within the combustion chamber. These burners have higher air velocity, more of the air introduced to the flame zone along the burner centerline, flame tubes to control recirculation, and flame tube slots or holes which control the amount and location of the recirculated flue gas. With these burners achievable NO_x emissions range from 40 to 65 ppm.

Routes to Sub-10 ppm

One key aspect of achieving the goals of sub 20 or sub 10 ppm NO_x is the nitrogen content of the fuel. Currently, heating oil has a nitrogen content of 150 mg/kg (.015wt%). At this level of nitrogen content essentially all of the fuel nitrogen is converted into NO_x and this contribution is about 23 ppm. In the BNL lab, combustion tests with a nitrogen free fuel, and a high performance, low-NO_x, blue flame burner firing into a cool-wall combustion chamber have yielded NO_x emissions of about 18 ppm with very low CO emissions.

Nitrogen-free Number 2 heating oil is not available on the market. The primary purpose of setting the goal based on a nitrogen-free fuel was to eliminate nitrogen as a variable in comparing different technologies and to demonstrate what might be achievable in the future. Ultra-low sulfur diesel fuels which are being introduced mostly for test and limited use purposes tend to approach nitrogen-free, as does kerosene.

From these results it is clear that a nitrogen-free fuel and very high quality recirculating burners can be used to achieve the sub-20 ppm goal but not the sub 10 ppm. One of the technical approaches under consideration involves increasing the recirculation rate with low-NO_x burners currently in a *commercial* status. The recirculation rate could be increased for example by

increasing the area of the recirculation slots in the flame tube. In combustion tests at BNL a burner was fired with an externally adjustable recirculation area. These steady state tests with a nitrogen-free fuel resulted in NO_x emissions under 10 ppm, below the target goal. Figure 1 shows the burner operating under the highest recirculation condition. Figure 2 shows the trend in NO_x emissions as a function of the recirculation area, expressed as a fraction of the flame tube exit area.

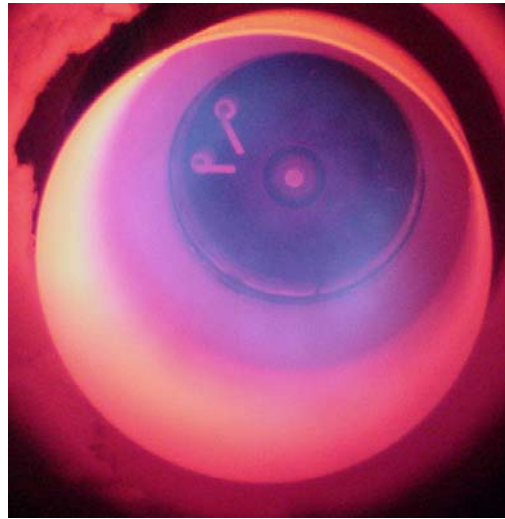


Figure 1. Photo of a low NO_x burner operating recirculation rates with very high

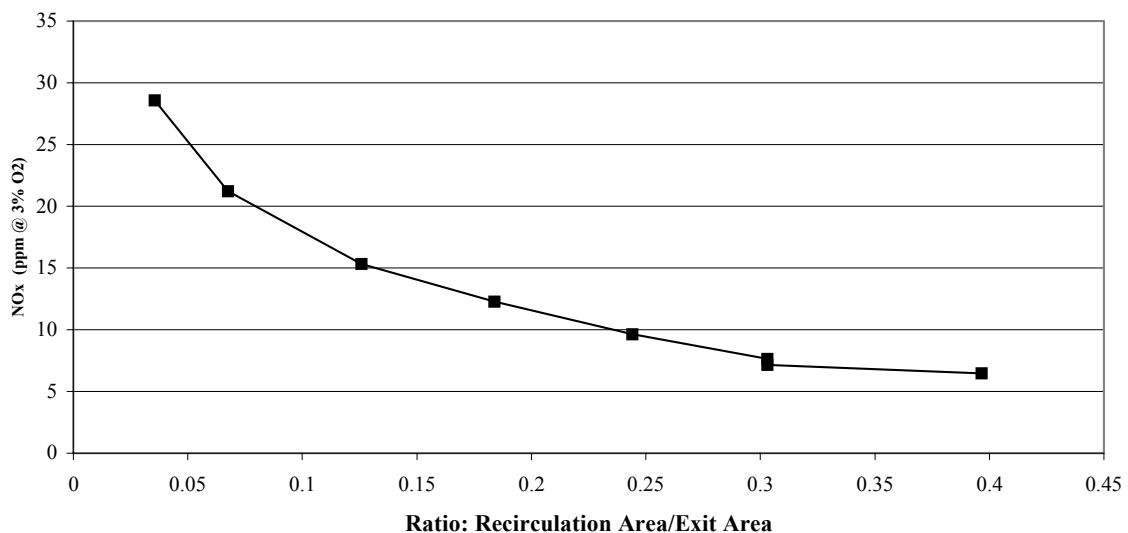


Figure 2 NO_x emissions measured as the recirculation area is manually adjusted in a low-NO_x burner

At the lowest NO_x points measured the burner was pulsing slightly, indicating that a stability limit was being approached. For all points except the one with the highest recirculation area, the

CO emissions were under 25 ppm. At the highest recirculation level (lowest NOx) CO was 63 ppm.

In practice a recirculating burner configured this way could not be started cold. Under cold conditions the rate of gas recirculation is considerably higher than when the burner is warm because of gas density differences. To achieve sub-10 ppm NOx in this way would require a special provision for starting, for example to reduce the recirculation rate only during the warm-up period. This might be achieved with a positional recirculation slide valve or aerodynamic valve closing off of the recirculation flow. An aerodynamic valve could be an air flow over the recirculation slots which prevents recirculated gas from entering the flame tube.

Another approach which could be taken is to combine internal gas recirculation with external gas recirculation and a condensing boiler might be a suitable platform for this. BNL is currently testing three different configurations of oil-fired condensing boilers. These have exhaust gas temperatures which are low – in the 120 F range and in some cases are intended only for use with low sulfur heating oil. This provides an exhaust gas which is relatively cool and which will have low potential for corrosion in the burner air housing. In this case, the advantage of external exhaust gas recirculation is that it might be easier to turn the recirculation gas flow off during the cold start period than with an internal recirculation burner. Prior tests at BNL and Carlin Combustion Technologies have shown the very strong impact that external recirculation can have on thermal NOx emissions in a residential system [3,5].

Burner head designs, which will never stop evolving, may provide an alternative route to achieving sub-10 ppm NOx emissions. One example which has been receiving considerable attention recently involves introduction of part of the combustion air through a circumferential array of ports concentric with the fuel nozzle. This approach is appearing in several European burners, particularly larger commercial burners. This approach allows dilution of the inner and outer parts of the combustion air with combustion products before these two parts mix to complete combustion [7]. In recent tests done cooperatively between BNL and Heat Wise, Inc. a low pressure, air atomizing nozzle was tested in a burner head with this configuration. Over firing rates ranging from 1.5 to 3.0 gallons per hour, NOx emissions in the 10 ppm range were achieved.

Another route which could be considered although with a greater level of complexity, is the combustion of a mixture of vaporized oil and air, within a porous ceramic matrix. Combustion within a ceramic body which can radiate heat away to relatively cooled surfaces has been well developed for ultra-low NOx gas burners. With oil the fuel must first be vaporized and mixed with heated air (and possibly recirculated combustion products). Currently, some very interesting development work is ongoing in the development of practical burners based on vaporizing oil in combination with radiant burners and very low NOx emissions have been demonstrated [8]. BNL has been conducting some tests of this approach for achieving the goals of this project in combination with ongoing studies of cool flames for fuel vaporization. Figure 3 shows a test burner flame inside of a reticulated ceramic burner. Measured NOx produced by this *flame* with a nitrogen-free fuel were roughly 6 ppm and CO was under 50 ppm.



Figure 3 Oil flame inside of a ceramic radiant burner at BNL

Conclusions

This work has been focused on exploring the technical feasibility of achieving NO_x emissions under 10 ppm with a nitrogen free fuel. The work to date has shown that this goal may be achievable, at least in the lab. Routes which have been developed towards achieving this goal include: 1) increased recirculation rates with current low-NO_x burner designs with special provisions for startup, 2) new burner head designs and 3) oil vaporization followed by combustion in radiant, porous media.

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Paper No. 02-03
Effect of Water Emulsion Fuels on NO_x Formation in Oil Burners

Victor J. Turk, P.E., Director of Engineering
R.W. Beckett Corp.
P.O. Box 1289
Elyria Ohio 44036
Phone: 440 353-6280
Fax: 440 353-6080
E-mail: vturk@beckettcorp.com
Internet: www.beckettcorp.com

Effects of Water Emulsion Fuels on NO_x Formation in Oil Burners

Victor J. Turk, P.E. – R.W. Beckett Corp.

Abstract:

Emulsion fuels where water particles are suspended in a middle distillate petroleum fuel matrix are effective in reducing NO_x formation in pressure-atomized oil burners. Varying the properties of the emulsions can be shown to have an effect on the degree of NO_x reduction. Two key properties include percent water in the fuel and the size of the water particles. The effect was measured on NO formation in the flame, thermal efficiency, and chamber temperature in a typical North American sectional cast iron boiler. The mechanism responsible for the reduction in NO formation appears to be reducing flame temperature. Additionally, the emulsion fuels reduce thermal efficiency of the appliance, although to a much lesser degree than they reduce NO_x.

1. Introduction

Of all the low level emissions from oil burners, NO_x is one of the most significant as a precursor to ground level ozone, the key component of smog. Although not currently regulated for residential oil burners in the primary North American market areas, this emission is receiving significant attention because of its potential environmental and economic impact. Previous investigations¹ have shown that burner and appliance configuration have the dominant effect on NO_x emissions, and would factor into control strategies. Additionally, fuel composition can have a significant effect. An important consideration here is the potential for emissions control without modifying the burner or appliance.

Investigations completed and reported during 2002 show that reduced sulfur and nitrogen petroleum fuels, bio-fuels and additized petroleum fuels have varying effects on reducing NO_x. Recently developed emulsion fuels where water particles are suspended in a middle distillate petroleum fuel matrix using chemical stabilizers and mechanical emulsification have been proposed to reduce NO_x. Additional work with these fuels shows them to have potential as a NO_x control strategy. This paper presents these results and postulates an underlying control mechanism with these fuels.

2. Fuel Factors influencing NO_x emissions

Elevated NO_x appears to be related to the presence of droplet flames (non-premixed diffusion flames), higher flame temperatures and the concentration of nitrogen during the reaction. Strategies that can reduce flame temperatures, avoid droplet flames in favor of premixed flames and minimize nitrogen are all useful in minimizing the formation of NO_x. These strategies are at work during the combustion of water emulsion fuels. A number of experimental observations are presented that demonstrate these effects in the following discussion.

Two key factors are of interest with water emulsion fuels – water content and particle size.

- a. Water content – Water is present in the fuel as a passive constituent in the combustion reaction. It absorbs heat as it passes through the combustion process, inhibiting the reaction, and reducing the attainable temperature of the total mass of the reactants and products of combustion as a function of the water content. As a passive constituent of the process, its presence can hinder the controlling NO formation reaction, because the water molecules effectively reduce the N₂ and O concentrations. This same effect can hinder the basic combustion reaction as well, and water content must be controlled so that normal burner

functions of light-off, stable operation and shut-down can be maintained. It also acts as a diluent or extender, and contributes an excess water fraction to the combustion products mass and energy balance. This has the effect of reducing thermal efficiency.

Water content also can influence the longer-term operability of a fuel in a burner-appliance system. Since water can have a corrosive effect in a fuel system that consists of ferrous components, the water must be properly contained so that the deleterious effects of water contact with ferrous fuel system parts is avoided. To avoid this direct contact, the fuels evaluated in this investigation were designed to encapsulate the water droplets with fuel as a chemically stabilized emulsion.

b. Water particle size – Particle size is a direct consequence of the emulsification process. It determines the dispersion of the water in the fuel, and in this way controls the *secondary* atomization of the fuel in the flame and hot chamber (after the primary atomization at the nozzle). The finer the water particle, and therefore the more dispersed the water is in the fuel matrix, the more sites there are for this secondary atomization. What is thought to occur is an explosive expansion of the fuel surrounding the water particles when the droplets are heated through the boiling point of water during the initial stages of the combustion process. This further reduces the fuel particle size, providing for more intimate mixing with oxygen, and more closely approximating a pre-mixed flame. For this to occur some relationship needs to be maintained between water particle size distribution and atomized fuel particle size distribution, although no attempt was made to establish that relationship as a part of this investigation.

3. Experimental considerations

This investigation was conducted in two different experiments: a first screening experiment using emulsions at two water contents and a constant particle size, and a second characterization experiment using emulsions at three water contents and three particle sizes. Two burners were used in both experiments, a conventional flame retention, yellow flame burner (FR-Std.) and a low emission, combustion gas recirculation (CGR) blue flame burner. (A third burner, a high performance yellow flame burner, was used in the screening experiment, but was dropped from the characterization experiment because its results were intermediate to the other two burners.) Both experiments were conducted using a three-section, cast iron, wet-base boiler of traditional North American design.

The different fuel conditions for the two experiments are described in Table 1. Selected fuel properties are listed in the Appendix.

Table 1 – Fuels used in experiments

<u>Experiment</u>	<u>Water content</u>	<u>Particle size*</u>	<u>Base fuel</u>
Screening experiment	10% 20%	Small	No. 2 Fuel oil (Emulsions & reference)
Characterization experiment	15% 20% 25%	Small Mixed Large	No. 2 Off-highway diesel (Emulsions & reference) No. 2 Fuel oil (Reference)

* Although particle sizes were measured throughout the development and manufacture of the emulsion fuels, specific details are considered proprietary. The particle size designations shown represent the output of two different processes, one that produced the Small particle size emulsions, and one that produced the Large particle size emulsions. The Mixed particle size emulsions are a 50:50 mixture (by mass) of the Small and Large particle emulsions.

Responses that were measured and evaluated in this investigation include:

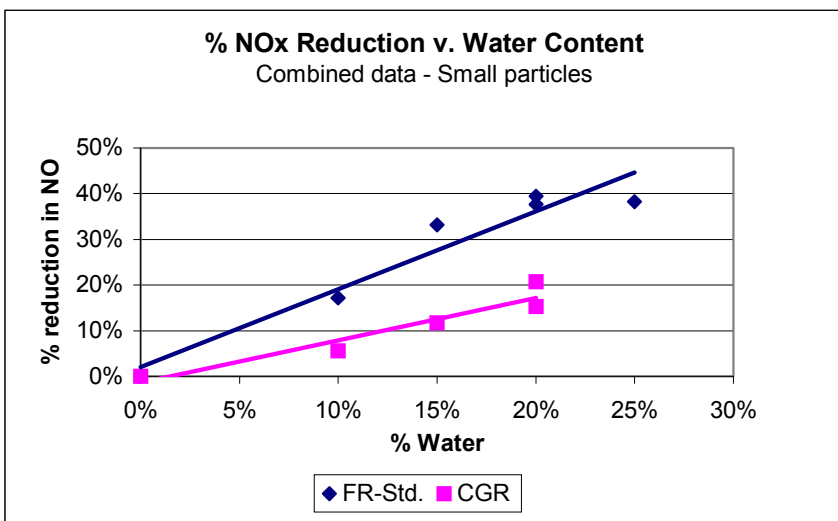
- NO at 13.3% CO₂ (3.0% O₂ equivalent)
- Thermal efficiency (measured or calculated heat input less losses and latent heat of vaporization)
- Chamber temperatures.

Combustion performance was measured using an infrared analyzer. Chamber temperatures were measured by inserting Type K (Chromel-Alumel) thermocouples through the vertical flue-ways and terminating them about 1.50 in. into the chamber (below the crown of the chamber). Three thermocouples were used in each flue-way, and the temperatures were averaged.

For thermal efficiency calculations, the pass-through emulsion water was treated as excess water for the mass and heat balances (much the same as air in excess of stoichiometric requirements is treated as excess air). Heat content (higher heating value) of the emulsion fuels was calculated from the base fuel heat content and the emulsion fuel water content after correlation of this relationship with multiple emulsion fuel samples. This was done because of inconsistencies in individual water content and heat content measurements that may have been confounded by the high water contents or the emulsifier content.

4. Water content

As water content increases, the reduction in NO_x increases. This effect was seen throughout the screening and characterization experiments, and both experiments were similar. Figure 1 shows the effect of increasing water content on the reduction in NO with data from both the screening and the characterization experiments. The data presented are all from the small particle emulsions for two reasons. The screening experiment used only small particle emulsions, and there appears to be a significant interaction between large particles and NO_x reduction (which will be discussed under the section on Particle size). With 20% water emulsions, NO_x emission reductions between 15% and 38% were achieved, depending on the burner used.



Difficulty in lighting off a stable flame in the conventional flame retention (FR-Std.) yellow flame burner with water content at 25% indicates a practical operability limit of 20%. Because of this difficulty, the 25% water emulsion fuels were not used with the low emission, combustion gas recirculation (CGR) blue flame burner.

Figure 1 – NO_x Reduction as a function of water content.

A similar effect appears with thermal efficiency – as water content increases, efficiency reduction increases (i.e., efficiency decreases). Figure 2 shows this effect, again using small particle emulsion data. In this case, the stratification of the data can probably be assigned to the heat exchanger deposition differences associated with the time difference between the screening and characterization experiments. Data points above the trend lines are from the screening experiment, while points below are from the characterization experiment.

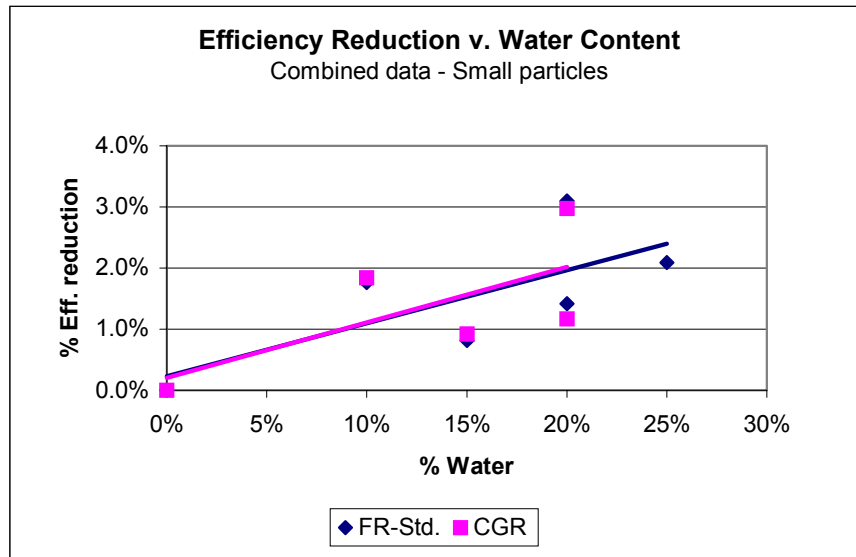
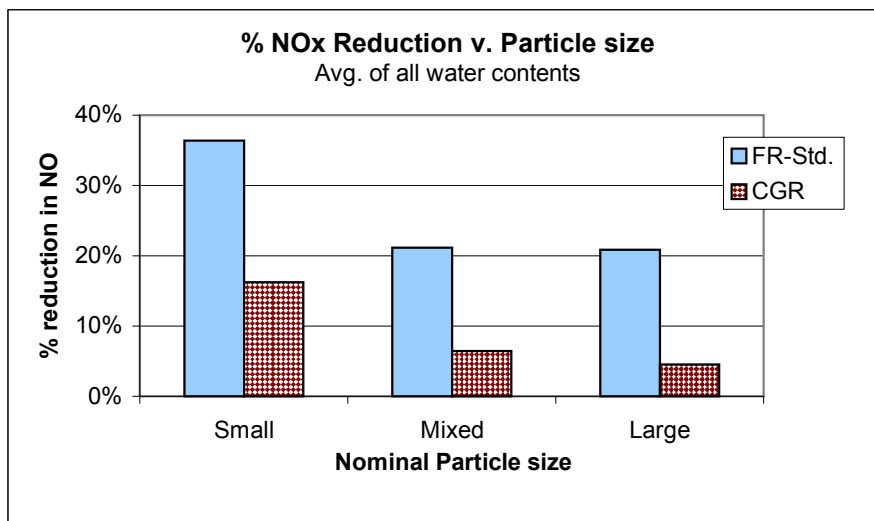


Figure 2 – Efficiency reduction as a function of water content

5. Particle size

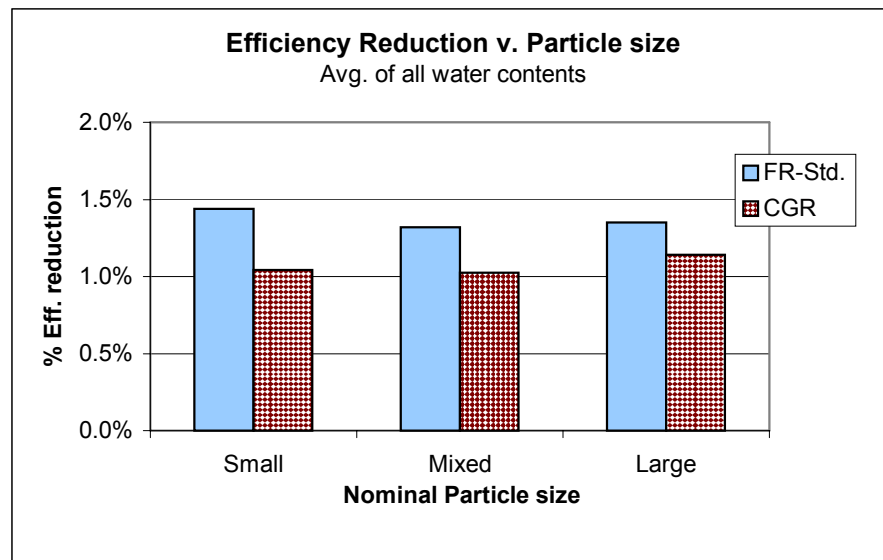
Small particle emulsions appear to be more effective in reducing NO_x emissions. Results from the characterization experiment presented in Figure 3 show the effects of particle size on NO_x reduction. The small particle emulsions are almost twice as effective as the mixed or large particle emulsions.



It appears that any large particles present are not only less effective in reducing NO_x, but their effect tends to dominate the effect of any smaller particles in the mixture. This may be due to the relative size of the water particles and the atomized fuel particles, and may relate to the ability (or inability) of the water particle to further atomize the fuel thought to be encapsulating it.

Figure 3 – NO_x reduction as a function of particle size

Particle size appears to have little if any effect on thermal efficiency.

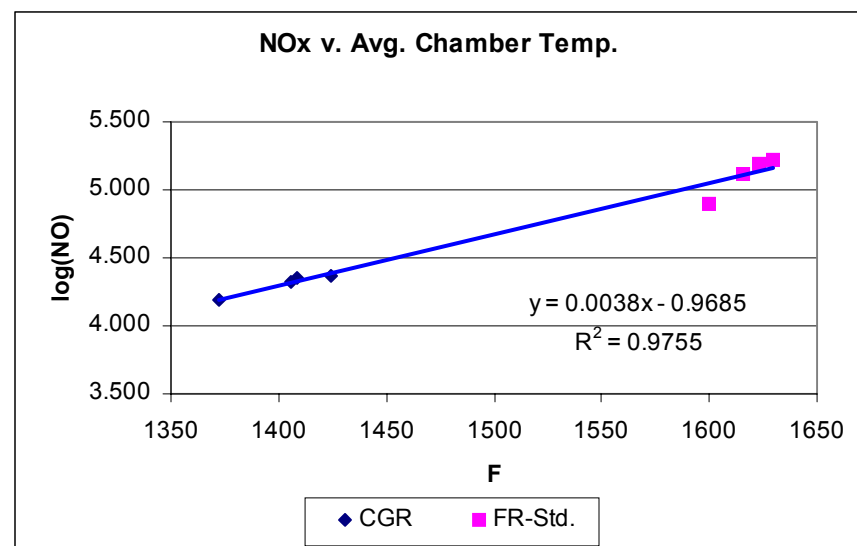


Results from the characterization experiment presented in Figure 4 show the effect of particle size on reduction of thermal efficiency. Although efficiency reduction increases with increasing water (as seen above) there appears to be little effect from particle size.

Figure 4 – Efficiency reduction as a function of particle size.

6. Chamber Temperature

After reviewing the effects of the different fuels on NO_x and efficiency reduction, subsequent measurements of chamber temperatures confirmed the relationship between chamber temperature (as an indicator of flame temperature) and NO_x concentration. Figure 5 shows this relationship for both burners used in the experiments.



The operating characteristics differ between the two burners, and this difference is reflected by the different temperature ranges and corresponding ranges in NO_x emissions. In spite of this difference, both data sets combine to create this relationship between the chamber temperature and NO_x that appears to hold across the full range of temperatures represented by these two burners.

Figure 5 – NO_x as a function of chamber temperature

7. Conclusions

Water emulsion fuels affect the formation of NO_x in pressure atomized oil burners, and can be useful as a strategy for controlling NO_x emissions without modifying the burner or appliance. The effectiveness of two characteristics is as follows:

- Water content at concentrations up to 20% (mass) can reduce NO_x emissions by between 15% and 38%.
- Smaller particles favor consistent NO_x reduction, probably due to an interaction between the water particle size and the atomized fuel particle size.
- Increasing water content reduces thermal efficiency, but to a lesser degree than it reduces NO_x emissions.
- Particle size appears to have little effect on thermal efficiency.

The mechanism responsible for this reduction appears to be flame temperature reduction, and the relationship between flame temperature and NO_x emissions appears to be continuous over a wide range of combustion process conditions.

Acknowledgement

The work presented in this paper was a joint effort by the R.W. Beckett Corporation and the Lubrizol Corporation. The author wishes to thank David Skursha for his help in devising the experiments, and for furnishing and analyzing the fuels.

APPENDIX

Table 2 - Selected fuel properties:

Property	Screening Experiment			Characterization Experiment				Ref. Fuel
	Base fuel	10% Emulsion	20% Emulsion	Base fuel	15% Emulsion	20% Emulsion	25% Emulsion	
% Water	0%	10%	20%	0%	15%	20%	25%	0%
Vis @40C (cSt)	2.27	3.41	4.60	2.61	3.91	4.51	6.09	2.71
Sp. Gr.	0.8567	0.8723	0.8840	0.8654	--	--	--	0.8661
Higher Htg. Value (Btu/lbm.)	19,264	17,127	15,625	19,302	<i>16,411*</i>	<i>15,446*</i>	<i>14,480*</i>	19,312
Sulfur (ppm)	3274	1683	1121	4552	--	--	--	3809
Nitrogen (ppm)	250	219	223	206	--	--	--	174

* *Italicized* values calculated from correlation analysis.

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1. Factors Affecting Oil Burner NO_x Emissions, V.J. Turk, R.W. Beckett Corp., Elyria, OH. Proceedings of the 2002 National Oilheat Research Alliance Technology Symposium, 2002.

Paper No. 03-03
Babington Airtronic Burner, Residential Heating / Hot Water Trial
Field Test Program 2001-2002

Gary L Sippin
Sippin Energy Products
234 main Street
PO Box 220
Monroe, CT 06468
Phone: (203) 261-3668
Fax: (203) 268-0769
E-mail: gary@sippin.com
Internet: www.sippin.com

**Babington Airtronic Burner
Residential Heating / Hot Water Field Trial
2001-2002**

Introduction:

Beginning in the winter of 1999/2000 three Babington Airtronic burners were installed in a variety of different domestic home heating applications in Connecticut. This field trial was extended to include 10 Airtronic burners by the end of the 2001/2002 heating season. The purpose of this field trial is to evaluate the performance and reliability of the Airtronic burner in a variety of typical US residential heating and hot water applications. The Airtronic burner was previously sold in Europe, and enjoyed an excellent record of performance and reliability. In addition, the Babington Airtronic burner has been successfully deployed by the US Marine Corps since 1996. Although these early deployments have proven successful, implementation in US home heating presents new challenges that have to be evaluated independently. In addition to evaluating the performance of the Airtronic Burner in the field, many additional tests have been conducted in our test facilities. The general areas of study are summarized below.

Combustion analysis

Flue gas analyzers are used throughout the testing to measure flue gas temperatures, excess air, Combustion O₂, Carbon Dioxide (CO₂), and Carbon monoxide (CO) levels. Combustion efficiency is derived from a formula based on flue gas CO₂ and net stack temperature. Our studies compared the Airtronic burners to the various high-pressure oil burners previously installed in these systems. The Airtronic burners tested throughout this program consistently operated reliably at high CO₂, low O₂, low excess air, and low carbon monoxide levels. In addition combustion efficiencies on virtually all systems tested were substantially higher than both the previous oil burner ratings and the manufacturer's claimed highest achievable rating.

The Airtronic burners have been able to run at high CO₂ levels reliably without producing soot or malfunctioning in any way. Traditionally, high-pressure burners become susceptible to sooting at high CO₂ levels. Therefore, it is customary for most oil burner technicians to set high pressure burners at low CO₂ levels, thus attaining a safe "head room" by which the burner can operate reliably without making substantial smoke. Standard flue gas analysis would also involve smoke testing with a litmus paper smoke tester. Because the Airtronic burner emits no measurable amount of smoke during its operation, we have generally not used smoke testers to test the Airtronic burners operation, instead we have elected to rely primarily on carbon monoxide measurements. Because carbon monoxide is indicative of incomplete combustion, we have used it extensively to fine-tune the Airtronic burner and to provide benchmark measurements. As a reference, conventional burners operate in steady state combustion at approximately 20 to 70-ppm carbon monoxide. Start up and shut down carbon monoxide readings run into the hundreds or even thousand ppm range. A properly adjusted Airtronic burner will operate between 0 and 10-ppm carbon monoxide with approximately 20 to 30 ppm on start-up and 40 to 80 ppm on shutdown, and again, there is virtually no measurable smoke in any of the operational phases of the Airtronic Burner.

Standard combustion efficiency readings are also taken upon installation and compared to readings from the previously installed high-pressure burner. Standard Airtronic burner installation CO₂ levels are generally set between 12-½ % and 13-½ % CO₂ for safe and reliable operation. Combined with lower capacity firing rates and generally large heat exchangers, combustion efficiencies generally range from a low of 87% to a high of 90.5%. Operating at these ultra high efficiencies, the burners achieve long burn cycles and very low stack temperatures. Combustion efficiencies in

excess of 89% require special consideration in venting. In these situations, sidewall venting is often preferred to minimize vent connector length and low flue gas temperature condensation. Soot deposits and particle emissions that accumulate on the heat exchanger, chamber and vent connector are also evaluated before and after the installation of the Airtronic burner. Emission particle build-up is evaluated on the heat exchanger to determine the estimated length of time that could be sustained between vacuum cleaning with the various different burner installations.

In general, the Airtronic burner emits virtually no carbon particle emissions and when tuned properly there is no soot or carbon deposits in any part of the heat exchanger or vent connector when using the Airtronic burner. The only noticeable deposits in heat exchanger or vent connectors are typically iron sulfate crystals that are the result of the inherent sulfur and #2 heating fuel combined with low flue gas temperatures.

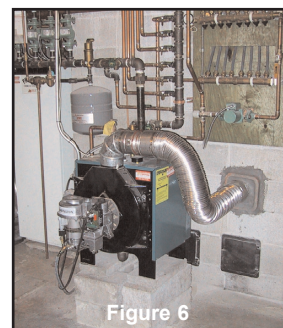
Venting systems

Many different types of venting systems have been used with the Airtronic burner successfully. These include lined chimneys (**Figure 6**), conventional masonry chimneys (**Figure 7**), and sealed (positive pressure) sidewall venting systems (**Figure 8**). Sealed combustion systems utilize the high static pressure blower of the Airtronic burner itself to pressurize the burner vessel and force flue gasses out of a vent connector, terminating outside the side wall of the home.

These systems are normally referred to as “sealed” combustion systems as they usually include a fresh air intake connected to the burner itself. In the case of the Airtronic burner, a flexible, fresh air supply line has been tested that can either be connected directly to the air inlet on the top of the burner or to a hole cut in the side of a sound suppression cover. In either case, it is easy to employ. The second type of vent connector installation we have encountered is

the powered sidewall vent. These powered vents are manufactured by several different manufacturers and operate by inducing draft by means of an exhaust blower. They cycle on (pre-purge) for approximately one minute. Once draft is proven with a draft switch, power is then supplied to the burner and ignition can take place. These types of systems are fairly common for sidewall venting because most existing boilers and furnaces are not designed to operate under positive pressure with sealed combustion venting systems. Many types of heat exchangers are not sealed well and leak vent gasses when operating in this mode. Therefore forced draft systems are often employed for sidewall venting. Unfortunately, these sidewall vent systems have not been well received in the industry as they are unreliable, difficult to work on, and noisy. Not to mention, expensive.

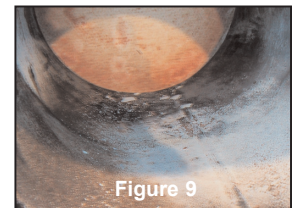
When a sealed combustion sidewall venting system is not possible, we have found that a small diameter (4”) chimney liner (**Figure 6**) works very well with the Airtronic Burner. Unfortunately most existing masonry chimneys are too large to operate effectively with low capacity burners allowing flue gas temperatures to cool below the condensing point. We have found that draft conditions have very little effect on the burners operation, consequently due to the very low emission and low odor emitted by the Airtronic burner, it has been our preference to run the burner with no draft to further enhance energy efficien-



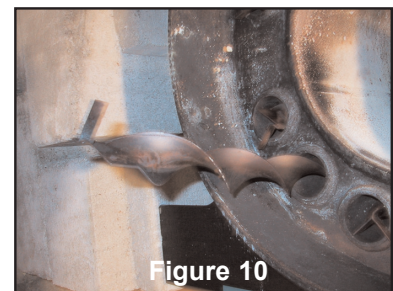
cy. Stack losses, also known as stand-by losses can account for as much as a third of all energy lost in a typical home heating system.

Low temperature condensing study

In many cases, flue gas temperatures are lowered to levels below what was previously thought to be acceptable or reliable. Under these circumstances, cooled flue gases may condense forming acidic residue. The affect of this condition is measured and monitored through the testing cycle. In our continued tests of low temperature operation, we are only able to study the immediate impacts upon condensing, i.e. a true study of the effects of condensing will have to be long-term (years) to determine the effect on metal components and venting systems. In general, there are two condensing issues that we contend with; Condensing in a boiler vessel itself, and condensing in the vent connector and/or chimney. In a boiler environment, condensing generally takes place with returned water temperatures below 140 °F. Under these conditions, a several minute start-up cycle at cool temperatures results in a continued build-up of iron sulfate on the inside of the chamber (**Figure 9**).



Again, this is extremely dependent upon the style of heat exchanger employed and how it is piped. A proper installation in a low mass boiler requires substantial by-pass flow to provide or maintain an adequately high temperature (140°) of the return water to the boiler. This will reduce the amount of iron sulfate build-up that occurs in the boiler. We have, however, noticed that this level of iron sulfate build-up from condensation is compounded at low capacity levels where the cool start-up period and burn cycle are relatively long compared to the higher-pressure burner. We have not noticed any significant corrosion build-up on the baffles section (**Figure 10**) of boiler/heat exchanger. As far as vent connectors are concerned, the single wall vent connectors may, if in a cool environment, condense and cause some liquid leakage out of the vent connector seams leaving a white powder residue in its place. Double wall flue connectors reduce this condition substantially. Generally speaking flue gas temperatures above 300 °F cause very little condensation problems where flue gas temperatures below 300 °F cause substantially higher flue condensing conditions. This is obviously compounded by the length, type and diameter of the flue pipe connector and the ambient air temperature of the room. Generally speaking, all tests are conducted using standard home heating fuel, which currently has a maximum sulfur content of .03 (3/10 of 1%). The adverse effects of condensation are caused predominantly by the conversion of SO₂ (Sulfur Dioxide) into SO₃ and SO₄. These sulfur compounds have a lower dew point and condense at approximately 200 °F. Therefore, low vent gas temperatures, when mixing with water vapor, will cause sulfuric acid and the corresponding iron sulfate deposits. In limited experiments with standard on-road diesel fuel (which has approximately 10 times less sulfur content), these sulfate deposits are substantially less and in some cases not visible. It has been an on-going effort in the heating fuel industry to lower sulfur content and an effort by the EPA is now underway to bring different varieties of middle distillate's down to lower sulfur levels. The predominant reason for this is airborne SO₂ levels, which are a known air pollutant.

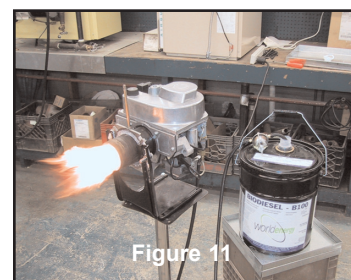


We have also done studies on the sulfates effect on overall system efficiency. We've concluded that the sulfate build up, although a detrimental condition, does not adversely affect the overall performance of the system at moderate levels of build-up. The iron sulfate tends to build-up in very thin

layers and flakes off, often falling to the bottom of the chamber. Unlike typical carbon soot build-up, it does not adhere to the sidewalls or the baffles in the same fashion and has a much substantially less detrimental effect on the thermal efficiency and transfer in the heat exchanger. In addition, the iron sulfate can be very quickly cleaned and actually removed with a damp rag without making a large mess of the heat exchanger.

Exhaust odors

Exhaust odors are a particularly high profile issue now-a-days in #2 heating fuel appliances. Especially when a direct or sidewall vent system is employed. In general, an increasing number of sidewall vent installations are now taking place due to the fact that the installation can be done relatively in-expensively without the need for an expensive masonry chimney and can be done fairly quickly. The unfortunate side effect of this is that high-pressure burners run with a great degree of smoke and smell and generally stain the side of the building with soot from the sidewall venting. This soot and smell is greatly increased upon start-up and shut-down and is further compounded by the fact that most high pressure burner installations are grossly over sized and continuously cycle. In particular, one installation that was noted in the field test at Hulls Farm Road in Southport was a particular trouble spot in regards to this issue. This particular home was an electric-to-oil conversion. The installers, due to limitations in the building were forced to install the direct power vent within three feet of the front entry way of the home. Although the power venter was not particularly esthetically displeasing, its continual staining of the side of the building and noxious odors have been extremely troublesome to the home owner since the conversion took place. In addition, the high levels of emissions of soot and sulfur deposits partially destroyed the shrubbery in that area as well. Upon installation of the Airtronic burner, combustion odors have decreased at least 10 times (according to the home owner) and are now barely detectable. This particular installation incorporates a power sidewall venter, which differs somewhat from what we refer to as sealed combustion venting. With a power sidewall venter, a vacuum is drawn (artificial draft) on the boiler or furnace that is vented out through the side of the building by means of a power blower. This type of system also incorporates a barometric damper which co-mixes hot flue gasses from the breach with cooler room air. The end result is that the exhaust being vented outdoors is approximately just slightly over 100 ° F. We have operated Airtronic burners with a variety of different fuels and, right now, the remaining exhaust odors associated with the Airtronic burner, we believe, are a result of sulfur in the fuel. We have confirmed this fact after operating the burner on several different types of ultra low sulfur fuels, including on-road diesel, K-1 kerosene, and soy bean BioDiesel B100 (**Figure 11**). Using these fuels, the odor that was noticeable with the #2 heating fuel, is nearly absent. As mentioned previously in this report there is an intention by the United States Environmental Protection Agency to lower sulfur levels in middle distillate fuels, although they are focusing mainly on on-road diesel fuel, there is a strong possibility that heating fuels will be required to achieve these low sulfur levels as well. In this quest to lower sulfur content, #2 heating fuel devices will benefit greatly not only the reduction in sulfate buildup but also the reduced exhaust odor emissions. Generally speaking, the sidewall vented exhaust generated by the Airtronic burner is so slight that, in most circumstances, it would go completely un-noticed.



Noise level

Noise levels of different burners are evaluated and compared to the Airtronic burner; in addition, several noise suppression systems for the Airtronic burner are also evaluated. Although noise level has been a relatively low-profile issue in the development of military applications, it continues to be a high priority issue with most home owners and residential applications. The un-modified military style Airtronic burners that were installed in the field test had no accommodation for noise suppression and were therefore considerably louder than the high-pressure burners that were removed. The high-pressure burners included models by Beckett, Carlin, and Riello, and all were reasonably quiet. The un-modified military Airtronic burners were designed with rearward facing air inlet covers, which amplified the motor noise. In addition, the motor silencers on the field test units had been removed during the manufacture process. Of all of the burners tested, the high-pressure burners employing covers the Riello Mectron was the quietest. To attempt to achieve this noise level we employed several different noise suppression covers for the Airtronic burner. This included a two-piece sheet metal cover (**Figure 12**) that was originally designed for a high pressure burner, as well as a molded plastic cover pictured in (**Figure 13**). When either type of cover was installed, the noise level on the Airtronic burner dropped significantly, and in some systems was now quieter than a high-pressure burner. As mentioned above, the predominant noise generated by an exposed Airtronic burner is high frequency motor noise, which is easily dampened by a modest amount of insulation within the noise suppression cover. Another important observation we made of the Airtronic burner is it's lack of low frequency noise.

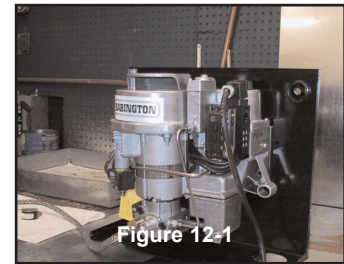


Figure 12-1

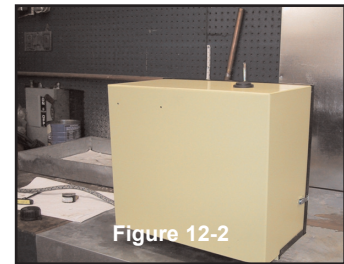


Figure 12-2

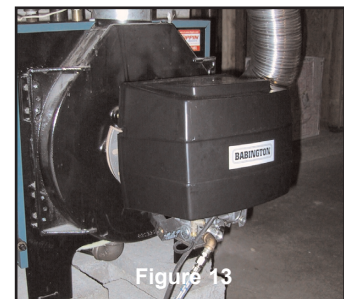


Figure 13

Most high-pressure burners operate with a relatively unstable flame, which tends to generate a low frequency rumble. This low frequency rumble resonates throughout the house and can be heard from a greater distance than high frequency noise. The Airtronic burner operates with a very tight and stable flame front, thus dramatically reducing low frequency rumble. Our conclusion is that the Airtronic burner, with very basic noise suppression will operate as one of the quietest burners in the field.

Material evaluation and metal erosion

Evaluations were made to the burners to determine the durability of the construction materials for all components of the burner itself. As the Airtronic burner was designed to exceed stringent mil-spec requirements for outdoor mobile use, it is basically over constructed for the typical benign environment of a residential home. However, we took time to evaluate several different components of the burner to determine the durability and longevity. In particular we focused upon the hot section of the burner, including the flame tube/air tube assembly. This was a particular concern of ours because in a refractory furnace environment, the reflected heat is extremely hot and the burner flame tube has to endure this heat for extended periods of time. After extensive run time on these components, we concluded that a minor amount of flame erosion did occur on the flame tube/air tube but stabilized after a short "burn-in" period. (**Figure 14**). We have also had the opportunity to examine flame tubes/air tubes that had been in other installations for over six years with constant

operation. We did not notice any extensive deterioration of these components.

An area of concern that we identified was regard to the various gaskets now employed in the Airtronic burner. The gasket used for the flow control module and sump are susceptible to damage and leaking if these components are ever removed for service.

We experienced several leaks in the flow control module and the fuel sump due to this problem. This problem, however, does not occur if these components are not regularly disassembled, i.e., in normal use leaks would not occur. These design issues have been identified by Babington Engineering and have been corrected in a subsequent design that incorporates an "o" ring cord instead of a flat adhesive gasket.

In addition, we also noticed on one occasion, that the adhesive back stripping of the gasket used for the flow control module can become loose and free floating, if not removed, and can then get caught in the fuel inlet in the flow control module, which we experienced in one burner.

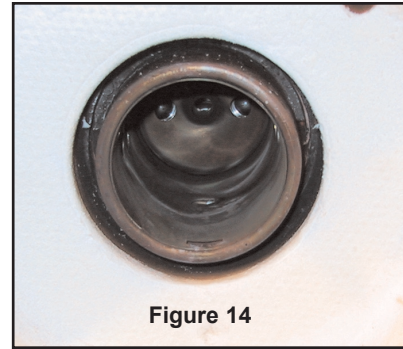


Figure 14

Electrical Component Durability

To date, we have used tow types of control on the Airtronic burner. The Satronic model #832 standard primary control box and the solid-state model 970. For the duration of these tests, we have only experienced one control box failure, which was a model 832 (Figure 15), contactor style control. It was subsequently replaced with a solid-state control on which we have not experienced any failure on at this point. In addition, one burner experienced a defective flow control switch and one burner experienced a defective fuel solenoid.

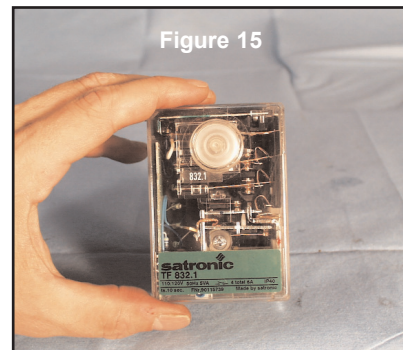


Figure 15

Performance

In general, the performance of the Airtronic burner has been extremely good. The only concerns we have had to date lie in some of the larger installations where extended burn times are needed to recover heat and hot water in low temperature conditions. In addition, most technicians and homeowners are not used to the long on-cycles of the Airtronic burner and have voiced concerns over the extended run period, despite the fact that this is, without a doubt, the most efficient way to operate a home heating system. There are however some challenges that have arisen pertaining to this particular issue, such as priority hot water zoning in the extensive use of clock thermostats with excessive set back ranges. In one instance, we had one installation that had several zones set back to 60° at night that were set to simultaneously cycle to 70° at a preset time in the morning. This combined with the normal shower hot water load, resulted in extensive heat up times and slow recovery. This situation was subsequently remedied by increasing the clock set back temperature to 66° and staggering the cycle on-times in he morning. A slight increase of firing rate was also implemented to compensate.

Ease of installation

Generally speaking, the installation of the Airtronic burner on all the test sites has been a simple operation. Removal of the high-pressure burner and cleaning of the heat exchanger is the first step. The second step involves installation of a standard 3-½ inch universal mounting flange. No particular attention is paid to the distance at which the flame tube is inserted into the chamber, as it does not seem to make much difference to the operation of the burner.

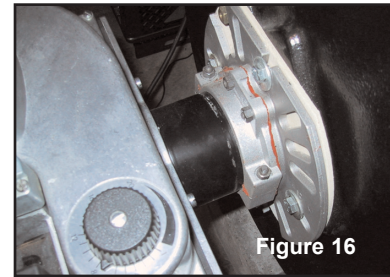


Figure 16

Wiring is easily accomplished by hard wiring the base of the Airtronic burner with a standard three wire lead (hot - neutral- ground) that supplies power to the high pressure burner. On some occasions some high pressure burners utilize controls that are turned on by a low voltage source (tt/thermostat). In an installation like this, a low voltage relay must be installed prior to the burner installation and then the high voltage wiring is then run from the control to the Airtronic burner.

Oil line connections are always converted to one-line systems and inter-connected with a steel braided line to the Airtronic burner. A disconnect fire valve is also installed prior to the braided steel line. On any installation where zero or positive pressure would take place, RTV silicone is added to seal the mounting flange. Average installation time for an Airtronic burner conversion from a high-pressure burner is approximately 30 minutes.

Fresh air supply

None of the field test installations have required outside fresh air supply. However, one implementation using a fresh air supply line was tested with the Airtronic burner. This involved installing a small, four-inch line attaching directly to the upper fan housing and air inlet of the Airtronic burner (**Figure 17**) for fresh air supply. This cannot be done easily on a high pressure burner due to the fact that the air inlet vents are mounted in a circular fashion in between the fuel pump and fan housing. This requires a cover, or complex shroud to attach to. It also make service of the burner difficult. Fresh air can also be supplied to the Airtronic Burner by attaching a flexible fresh air supply line to a noise suppression cover in the same fashion. It also must be noted that the need for fresh air supply in the Airtronic burner is far less than a conventional burner.



Figure 17

This is due to two primary reasons. 1) The Airtronic burner runs at low capacity. Fresh air requirements are generally calculated based upon the BTU input rating of the burner. 2) The Airtronic burner can function with far less excess air and combustion O₂ than a conventional burner, allowing it to operate safely and reliably at low combustion air levels.

Ease of repair and troubleshooting

Even given the limited scope of this field test, it is evident that the Airtronic burner is extremely easy to trouble shoot in the field. In real life practice, a malfunctioning Airtronic burner would most likely simply be replaced with another Airtronic burner in the field in less than a minute while the malfunctioning burner is brought back to the shop to be repaired at a later time. However, in the field, several key features of the Airtronic burner make it extremely easy to repair in the field.

1. The burner can very easily be removed from its mounting flange by simply loosening two

mounting nuts. This allows for quick examination of the flame tube and atomizing chamber.

2. A test box can be installed in place of the primary control to immediately isolate problems with motor, photo-cell, air solenoid, and power pack.
3. Fuel supply/fuel flow problems are also extremely easy to diagnose. We've found that the quickest way to diagnose a fuel problem is by simply removing the flow control module cover and insert and examining the fuel flow passing into the flow control module. In contrast and high pressure burner would require the dis-assembly of the fuel line or nozzle line to inspect for fuel flow or pressure.
4. The photocell is also extremely easy to test as it can easily be removed from the burner and checked for function. In addition, the fuel solenoid can also be tested simply by unplugging its wire in place.

All in all, with basic training a technician should be able to trouble shoot and repair an Airtronic burner in a fraction of the time of a conventional high-pressure burner. Simple hand tools, a diagnostic control box, and a few gauges are all that is needed to diagnose the majority of all Airtronic functions.

Fuel pump system

The fuel pump system on the Airtronic burner has been of great interest to the oil heat community and for many important reasons. The fuel pump system of the Airtronic burner is unconventional in comparison to high pressure burner fuel pumps. The basic function of the fuel pumping system on the Airtronic burner revolves around its necessity to operate in a one-line mode.

Several test cases were conducted to establish dry priming and long lift capabilities. It is a known fact that long lift and high vacuum conditions will cause a high-pressure burner to fail due to out-gassing of the fuel, and subsequent pump cavitation. The Airtronic burner pump system has been able to successfully operate in high lift, long pull conditions due to its ability to purge air from its systems. In addition, the fuel does not need to be pumped at high pressure from its outlet side, and in fact, only operates at an outlet pressure of 5 to 6 psi.



In summary, Airtronic fuel pump system has been able to successfully function in all residential test applications we have used to date. This includes several in-door tank installations and over-head in-door tank installations, outdoor two-line conversion system, and a multi burner installation system. Technicians, who have installed the Airtronic burner, have drawn some similarity of the Babington Airtronic Fuel Pump system with the device known as the Tigerloop®. A TigerLoop® is a device used to purge air and convert two line oil systems to one line function. When thought of in this way, many oil burner technicians become immediately comfortable with the function of the Airtronic burner's fuel pump system. In addition an extremely important feature of this system is its ability to self prime in a single line configuration. Current single line systems require manual pump bleeding to prime.

Fuel Filtration and Fuel Contaminant

In general, the fuel filtration systems used on the Airtronic burner test installations, have remained largely unaltered. In other words, the standard 99 styles or 1A25, or 1A30 oil filter cartridge was left in place for the Phase 1 test period. However, one installed burner was operated for approximately one year with no oil filtration whatsoever and in a recent installation a #200 screen style strainer was installed in a #99 standard oil filter cartridge canister. To date, we have not experienced any burner shutdowns due to fuel contaminate. We feel that the #200 screen strainer would adequately handle the filtration for the Airtronic burner as it would remove any large or hard particles that could possibly cause damage to the gear set or pump itself.

In general, there are no small orifices throughout the entire fuel pump system that would be susceptible to clogging under normal conditions.

We have had one experience where a modest amount of water was mixed with the fuel where some water continues to be held in emulsion. In these circumstances, the burner has run without failure and not exhibited any detrimental effects. However, when run with the water-contaminated fuel, the combustion does exhibit a bright orange corona around the edges of the flame, which are indicative of the water-contaminated fuel.



Domestic Hot Water Recovery

This is one of the areas of greatest concern with the Airtronic burner in the general implementation of low capacity burners. As most of our field tests involve boilers that are either directly or indirectly making domestic hot water, the performance has been closely monitored. At this time, the only noticeable performance depreciation exhibited is generally in the form of hot water recovery. In the case of the indirect hot water heater, the recovery times have been extended roughly by 20% to 50% depending on the application. In most cases, the home occupant has not noticed the slower recovery time due to the fact that the storage capacity of the hot water heater is often adequate to meet the needs of the homeowner's domestic hot water demand. Therefore after hot water is used, the regeneration period is irrelevant to the homeowner, as the hot water needs have already been met. These systems, however, have to be optimized to produce hot water at the highest efficiency level in consideration of the low capacity operation. We have employed priority zoning to assist in faster domestic hot water recovery. This is an electronic relay that provides 100% heating capacity to the indirect hot water heater shutting off circulators for all remaining heat zones in the home. This will provide 100% recovery to the indirect hot water heater for a brief period of time. In the short period of time that the water heater has operated, the home temperature may only drop by a degree or two, which is usually not noticed by the homeowner. In addition, we have installed mixing valves on several hot water heaters allowing them to operate at higher temperatures.

Reductions in Fuel Consumption

At this point it is very hard to characterize the actual fuel savings realized by the Airtronic burner, as there are many variables that exist in making an accurate, comparative analysis. Unfortunately many of those analysis would take years to accomplish. In general based on K-factor calculations so far, we have concluded that the approximate fuel consumption savings of the Airtronic burner (when replacing a conventional high-pressure burner in a conventional boiler or furnace) are approximately 15 to 20%. When installed in a high efficiency heat exchanger, or with high efficien-

cy radiation, we estimate savings to be as high as 30 to 50%. These energy savings are predominately attributed to three distinct areas.

1. Low capacity operation. By accurately load matching the burner to the homes actual heating needs, long burn cycles can be achieved. This reduces stack losses, as well a jacket, and room ar losses. In addition, the Airtronic burner is seasonally adjustable with parts changing, which means it's burn rate can further be "dialed-in" to achieve the most efficient operation.
2. High combustion efficiency. High CO₂ and low stack temperature yield high net combustion efficiencies. This means that more heat is absorbed by the heat exchanger, and less heat is vented out the chimney.
3. Lack of particle emissions result in clean heat exchangers that operate at high efficiency all the time. Burners that produce soot rob the system of it's ability to transfer heat, therefore allowing much heat to escape up the chimney.

Reliability & Service

This is an extremely important evaluation that we are trying to estimate at this time. Due to the high cost of annual maintenance required on high-pressure burners, this particular study took on a role of high importance. We estimate at this point that the recommended service interval for the Airtronic burner (in a boiler) is approximately 2 to 3 years, depending upon what type of boiler it is installed in. In a warm air furnace, we feel an acceptable interval should be between 3 and 5 years. We have arrived at this conclusion for several key reasons:

1. The requirement for annual service on a high pressure burner, lies largely due to the fact that it's nozzle will require replacement after, approximately, 1,000 gallons of oil has passed through it. The Babington Airtronic Burner has no nozzle thus eliminating this required maintenance step.
2. An in-line oil filter in a two-line system will need to be replaced every year. A Babington Burner employing #99 canister with a #200 screen strainer would only require a cleaning (not replacement) about every 5 years depending upon fuel quality.
3. Soot generated by excessive start-up and shutdown cycle will have to be vacuumed approximately every one to two years. The Airtronic burner generates no carbon soot, and only a minor amount of iron sulfate scale, thus greatly extending the periods between needed vacuum cleaning. Our estimate is 3 years on a standard hot water boiler, and 5 to 7 years on a warm air furnace.

In addition to extending the service interval, we are also eliminating several hours of work normally associated with the service of a high pressure burner. The periodic service of the Airtronic burner should take less than 30 minutes to accomplish.

We feel that the general reliability (non-scheduled service) will be greatly improved over that of a high pressure burner. All due to the items mentioned above. It is a well know fact that fuel contaminates are a large portion of service calls in most burner failures, in addition, soot related calls are equally as problematic. To date, we have not experienced one fuel or soot related failure with an Airtronic burner, in addition, we have never experienced a delayed ignition problem, which is quite common among nozzle type burners.

Acceptance by the industry

How does the industry and consumer public view this technology? As expected, the industry has approached this technology with a degree of trepidation. This is well justified due to the fact that several unsuccessful burner designs have been introduced in years past that failed with dire consequences. In addition, the stagnant nature of the industry has left most oil burner technicians and professionals with the notion that what they have is as good as the industry will ever get. However, when the basic design concepts of the burner are explained to a technician, the acceptance comes quickly.

Clearly, the biggest concern of the industry lies in the Airtronic burners low capacity firing rate. The industry has grown so accustomed to over-firing that most oil burner technicians do not believe that a .50 GPH burner can adequately heat an average sized home. Unfortunately, some homes with older boilers and poor hot water systems will require higher firing rate burners, however all of the test sites we installed were able to get by with the low firing rate burner. The three largest areas of malfunction on a domestic oil burner, revolve around fuel contaminant, generation of soot, and ignition problems. Virtually all of these problems can be traced back to the poor atomization of the high-pressure nozzle. Once it is fully understood that good atomization is fundamental to good combustion, technicians begin to see the light. They begin to understand that burners can function on poor quality fuel and continue to operate cleanly, without soot, and fire with reliable ignition, provided good atomization is in place. In general, reception by the technical community has been very positive, however, a bit cautious.



On the consumer side, we have not experienced any fear over the technology. 95% of all consumers that we have discussed the burner with are enthusiastically excited about using it and have voiced positive support for the purchases of this burner even at higher prices than the highest quality high pressure burners available. Their concerns largely revolve around the high reliability of the function of the burner, fuel conservation, and lack of combustion odor.

Firing Rate of Evaluation:

This perhaps is one of the final key areas of consideration in evaluating the Airtronic burner. In most field test applications, we have experimented with boiler domestic hot water heater applications that require significant btu heat loads requirements when all zones are calling (in low temperatures) and a simultaneously call for domestic hot water is also needed. In these rare instances, unfortunately, the physics dictate that a slightly larger burner capacity is needed to handle the load. In 3 of our field tests, where the sq. footage of the home exceeds 3,000 (up to 4,000 sq. feet) we feel that a firing rate of approximately .75 to .80 will be required to handle peak load demand for boilers utilizing indirect hot water heaters. At this time we feel that on large, sq. footage applications (above 3,000 sq. feet) that employ tankless coil type water systems, there will be slightly diminished performance that may or may not be noticeable to the homeowner. In these cases a retro fit application would require a firing rate of approximately .90 to one gallon to sustain acceptable consistent domestic hot water output under severe cold weather conditions. In the later part of January, we received two high output atomizing chambers for test from babington Engineering. They were rated at approximately .85 GPH and 116,000 BTU's per hour. They are currently being evaluated.

General Summary

In general summary, the field test of the Airtronic burner has proved to be an exciting project. We have experience first hand many milestone achievements in efficiency, reliability and performance. It is an introduction of cutting edge technology to an industry so desperately in need of technological improvement. It has opened not only our eyes but the eyes of many consumers, and has led us to believe that oil heat has a very bright and promising future. A future where oil fired appliances are small, quiet, clean, reliable and environmentally friendly. These are the tools needed to change the oil heat industry.

Paper No. 04-03
microCHP [Cooling Heating and Power Generation] –
The Next level of Efficiency

Thomas A. Butcher, Ph.D.
Brookhaven National Laboratory
Building 526
12 North Sixth St.
Upton, NY 11973-5000
Phone: 631-344-7916
Fax: 631-341-2359
E-mail: butcher@bnl.gov
Internet: www.bnl.gov

microCHP – The Next Level in Efficiency
Thomas Butcher, Ph.D.
Brookhaven National Laboratory

Abstract

Most electricity in the U.S. is generated in central station plants where the fuel-to-electric conversion efficiency is on the order of 35%. With distributed power generation the waste heat can be used for space or process heating or to drive absorption cooling, leading to much higher system efficiency. There has been, over the past few years great interest in such projects in the commercial and industrial sectors. “microCHP” refers to the generation of electric power in single family homes in heating appliances. This paper provides an overview of the technologies being developed for this, the world-wide activities, the potential savings and the role that oil can play.

Introduction

Most electric power is produced in large central stations where the fuel to electric conversion efficiency is about 35%. The unused fuel energy, almost all as heat, is either rejected from the stack (12%) and rejected in a water condenser to a large body of water or to the air in a cooling tower (53%). In the U.S. the energy wasted in central power plants is the equivalent of 4 billion barrels of oil each year. At a price of \$25/barrel this would represent \$100 billion/year. Cooling Heating and Power (CHP) systems are being developed to generate electric power at distributed sites where waste heat can be directly used for space, process heating, water heating or for cooling. Most of the attention has been focused on large commercial and industrial sites where the economics are attractive and conventional power generation technologies such as engine generators, steam turbines and gas turbines can be used with modular heat recovery and absorption cooling equipment. At present there is a major DOE-sponsored program underway to develop fully packaged CHP systems for these applications [1].

On the residential scale there is also interest in producing electric power and possibly cooling in integrated home heating appliances. While the technology and product development is in a much earlier stage than for the larger systems, there is a great deal of activity which seems very likely to lead to an impact on the market over the next 10 years. On the residential scale this has been termed *microCHP* and a variety of technologies are being considered. While much of the present attention is on gas, most of these technologies can also be easily used with oil.

This paper provides an overview of the most significant microCHP product development efforts underway. For these technologies specific companies and products are included here only to provide examples.

microCHP Technologies

For residential boiler or furnace with a firing rate of 0.75 gph the heat input is 105,000 Btu per hour. Assuming a fuel-to-electric efficiency of 15 % the electric power production would be 4.5 kW. A typical home has a normal maximum demand of 5 kW and a system with a fairly simple, low efficiency power cycle could meet essentially all of the power demand, when the unit is firing. The approach being taken in essentially all products nearing commercial status is to have a smaller capacity than the peak electric demand and operate the system fully in parallel with the

incoming utility company electric supply. These systems are all *heat-led*. This means they run only when there is a heat demand and only produce electric power at these times. To be economically attractive these systems need to run as much as possible so they are installed with a low oversize factor. Frequent, short operating cycles are very undesirable. Fuel energy not used to generate electric power is used for heating and the overall system efficiency is very high, constrained only by venting concerns as in a conventional boiler or furnace. For example: a 0.75 GPH appliance with 2 kW electric power output and a flue gas analysis efficiency of 85% would produce 82,400 Btu per hour of heat. However, the efficiency accounting can be done another way. In some approaches that calculate an appliance efficiency which considers electric power consumption, the electric use is multiplied by 3 to provide consideration of the efficiency of central power plants. This converts the power demand to primary energy use. If the same rule were to be applied to power generated in a home appliance, considering not the energy value of the power produced but the avoided fuel use in a central station, the efficiency of this non-condensing appliance would be 98%. No serious consideration has yet been given to an efficiency definition for microCHP systems.

By sizing the microCHP systems well under the peak electric demand of the house issues of net-metering to the utility are avoided. Electricity sold back to a utility, where allowed, is sold at a price very much lower than the residential purchase price. The greatest value to the homeowner is in reduced demand of electric power. Also, operation of these systems for backup power during a power outage has not been a priority for microCHP product developers although some are planning this capability, possibly as an option.

Four types of technologies are considered to have the highest potential for commercialization and are discussed below. These include: Stirling engines, Rankine cycles, fuel cells, and conventional reciprocating engines.

Stirling Engines

This is a piston type engine which has combustion external to the cylinder. Heat is transferred in and out of the cylinder space above the piston very rapidly to drive the engine motion. External combustion allows these engines to have emissions as low as conventional residential heating boilers or furnaces.

At present it has been reported that eight companies are actively developing Stirling engine microCHP appliances [2]. One example is Microgen / BG Group from the U.K. [3]. This system has a piston directly connected to a *linear generator*. The target product has a power output of 1.1 kW and is shown in Figure 1. The product planned to launch in 2004 is gas-fired and the heat recovery section is a condensing boiler. The system reportedly can be converted to oil in the future. To date the company has reportedly invested over \$30 million dollars in product development.

Another example of a Stirling engine is shown in Figure 2. This unit is made by Whispertech in New Zealand [4]. The nominal output power is 0.75 kW and the heat output is 6 kW or 20,500 Btu per hour. This technology uses a *wobble plate* to convert reciprocating piston motion to rotary motion to drive a generator. The company currently produces an oil-fired version of this for marine and remote home applications.

Rankine Cycle Engines

A simpler technology than Stirling engines is Rankine cycles. One familiar example of this is a steam turbine and two companies are currently close to commercial status with products related to this approach.

Figure 3 illustrates one system under development by a German company, Enginon [5]. Heat from the burner flame generates steam which drives an expander (like a turbine) coupled to a generator set. After the expander, the steam condenses transferring heat to the water in the conventional home hydronic loop. The fuel to electric power efficiency is reported to be 20 percent and the target home product power output is 0.5 to 6 kW. The concept is derived from an automotive origin and the company reports 500 man years of development effort has been invested to date. The product, shown in Figure 4, is expected to be on the market in 2004.

A second steam- cycle concept is under active development by a U.S. company – Climate Energy [6] and the flow circuit for this system is shown in Figure 5. A very small volume of water is heated under pressure and then injected into the center of an expander through a pressure drop device. Part of the water flashes into steam which drives the expander and connected generator. After the expander the low pressure steam transfers its heat to the hydronic loop or return air. In this case there is also a second heat exchanger within the boiler or furnace to capture more heat from the combustion products before the boiler exit. This concept is being considered for boilers and furnaces with power output ranging from 1 to 10 kW. A warm air furnace prototype being developed is shown in Figure 6.

A third concept in this category involves a similar cycle but the water / steam system is replaced with an organic working fluid. The flow arrangement used is shown in Figure 7. This concept is being developed by a U.S. company Inergia [7] and the first commercial system is expected to be introduced in England in cooperation with the Energetix Group Limited. Figure 8 shows a system prototype which produces 3.4 kW of electric power and 116,000 B per hour of heat.

Fuel Cells

Fuel cells relevant to the microCHP market include PEM, and Solid Oxide types. PEM (Proton Exchange Membrane) fuel cells operate at low temperatures – 175 F. This gives them the advantage of rapid startup and this feature makes them the choice for automotive applications. PEM fuel cells are under intensive development for this application. Solid oxide fuel cells operate at much higher temperatures – 1400 F. This higher temperature results in a slower warm-up time.

All fuel cells require reforming of common fuels such as gas or oil to produce electric power in the cell *stack*. PEM fuel cells typically have a separate reformer module which includes discrete steps such as partial oxidation, a shift reactor (to increase the hydrogen yield) and CO conversion. These fuel cells are easily poisoned by CO in the feed gas to the stack and it must be reduced to very low levels in the reformer section. In prototype systems natural gas is often used as the fuel feed although a considerable amount of work has also been done on liquid fuels including gasoline, methanol, and heating oil. In summary, with a PEM fuel cell, due to the high

quality requirements for the stack feed gas, fuel reforming is a very critical step in the process which creates some real challenges for fuel oil. Solid oxide fuel cells also require fuel reforming prior to the stack section but, because of the higher operating temperature, this type of fuel cell is much less sensitive to the quality of the stack feed gas, practically making this more compatible with oil.

Several companies are actively working on residential fuel cells of the PEM and solid oxide type. For example – Figure 9 shows a system nearing commercial status and produced by Sulzer Hexis in Switzerland [8]. This unit is a solid oxide fuel cell with an electric power output of 1 kW. Their first market introduction is planned for natural gas although the company is very actively working on an oil unit also. The unit is intended to start in the fall and run continuously until spring. The thermal output is about 10,000 Btu per hour and this is supplemented by a second burner / heat exchanger which comes on and off to meet the changing house heat demand during the heating season. This approach overcomes the problem of the slow warm-up time of the high temperature solid oxide cell. The company is very aggressively developing a market in Europe. They plan 400 field trial units in place by the end of 2003 and report that they are on target to complete this.

Conventional Reciprocating Engines

These engines have been the most popular choice for small and large CHP systems because of cost, reliability, and familiarity. Their major drawbacks are noise and air pollution emissions. However, several companies currently have products on the market and this approach may be an important market factor into the future. For one example, the German company Senertec [9] currently offers both gas and oil-fired microCHP systems in Europe. The gas engine is a *lean burn*, low emissions type with an exhaust oxidation catalyst. The oil-fired (diesel) unit has an exhaust manifold filter to capture soot. Every few hours the engine is forced to run at higher than rated load to increase exhaust temperature and burn off the captured soot. The company reports 6000 installations in Europe, mostly in multifamily homes and about half of the installed units are oil.

Economics of microCHP

At the present time the economics of microCHP cannot be accurately evaluated because of the limited real market penetration. Only after products have matured and purchase, installation and maintenance costs are really known will accurate economic analysis be possible. At present, manufacturers projections show payback periods on the order of 3 years. A major study has been completed of the potential for microCHP in Europe including a consideration of the economics [10]. Based on this it is estimated in the study that the number of microCHP systems installed in Europe will be 5 to 12.5 million units by 2020.

Conclusions

Distributed generation in general offers the potential for very large improvements in the way in which energy is used in the United States. At the smallest scale microCHP technologies can implement distributed generation at the home level and could, in the future, dramatically change the nature of home “heating” appliances. While the economics and practical implementation of microCHP are certainly not yet proven, there are in progress several very substantial commercial

development efforts. These could provide important opportunities for the oilheat industry in the future.

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Figure 1. Illustration of a Stirling engine microCHP product installed in a kitchen. Source – Microgen



Figure 2. Illustration of a Stirling engine microCHP product. Source – WhisperTech

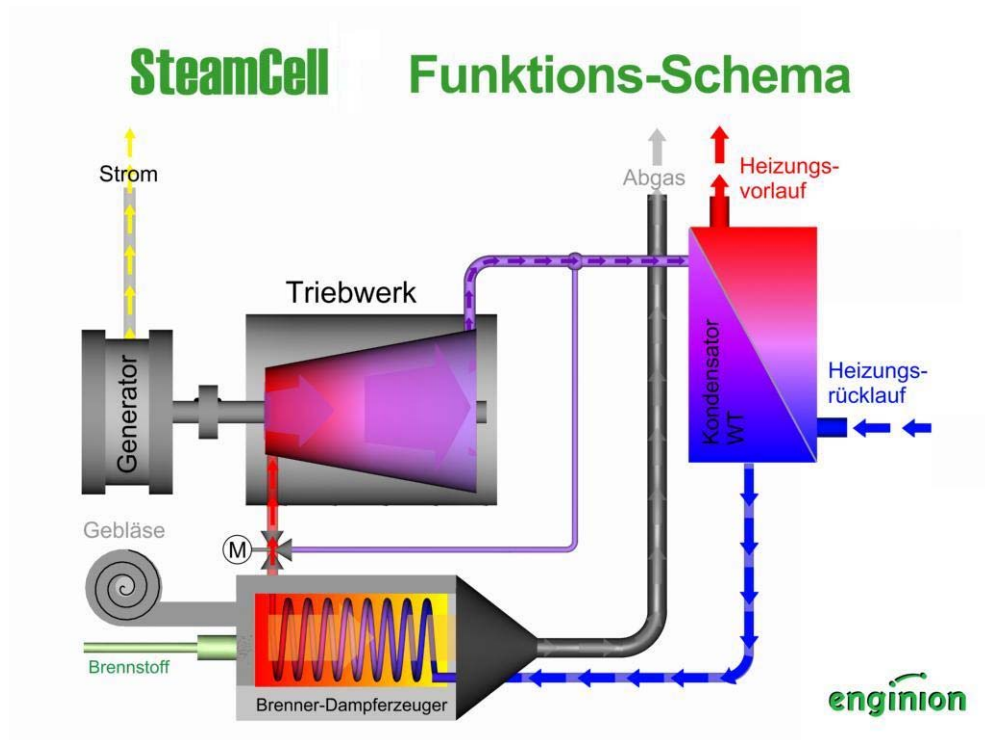


Figure 3. Schematic arrangement of a Rankine cycle microCHP product. Source – Enginion.



Figure 4. Illustration of a Rankine cycle microCHP product. Source – Enginion.

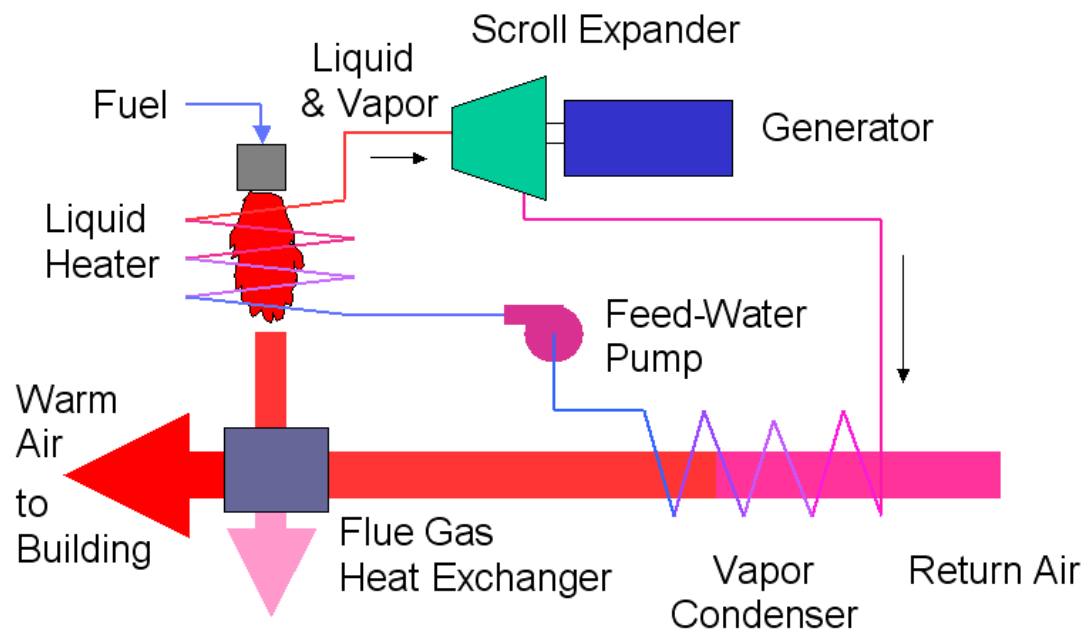


Figure 5. Schematic arrangement of a Rankine cycle microCHP product. Source – Climate Energy.



Figure 6. Illustration of a Rankine cycle microCHP product. Source – Climate Energy.

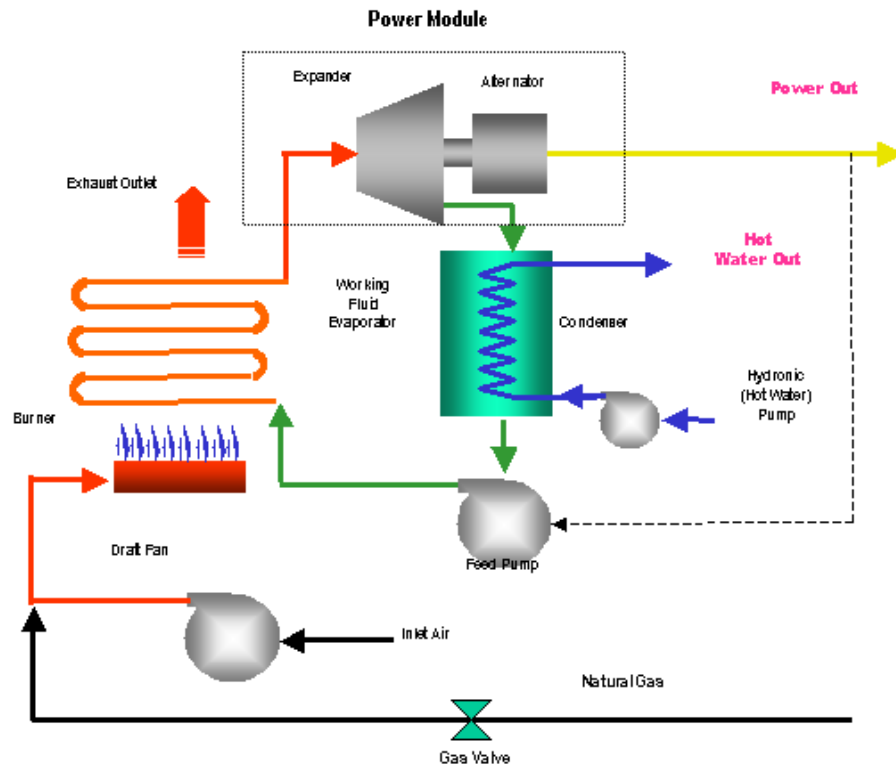


Figure 7. Schematic arrangement of a Rankine cycle microCHP product. Source – Battelle



Figure 8. Photo of a Rankine cycle microCHP product. Source – Battelle.



Figure 9. Photo of a solid oxide fuel cell based microCHP product. Source – Sulzer Hexis.

Paper No. 05-03
National Oilheat Research Alliance Fuel Performance Research Update

Wai Lin Litzke
Brookhaven National Laboratory
Building 526
12 North Six Street
Upton, NY 11973
Phone: 631-344-7153
Fax: 631-344-2359
E-mail: wlitzke@bnl.gov
Internet: www.bnl.gov

Robert Hedden
Oil Heat Management Services
RFD 1, Box 1819
Pawlet, VT 05761
Phone: 802-325-3509
FAX: 802-325-3437
E-mail: bhedden@sover.net

National Oilheat Research Alliance Fuel Performance Research Update

Wai Lin Litzke, Brookhaven National Laboratory
and Robert Hedden, Oil Heat Management Services

Introduction

A stable fuel with consistent quality is essential for reliable, efficient operation of heating systems. This report is an update on what we have learned so far, and what we are currently studying. It is also the beginning of what will eventually become a comprehensive Fuel Performance Manual.

The Oilheat Industry's top two service priorities are improved reliability and reduced heating equipment service costs. A significant number of unscheduled no heat service calls are caused by inconsistent fuel quality, fuel degradation, and contamination.

The objectives for the program are to:

1. Clear up the idle conjecture about the causes of the fuel problem. We hope to correct widely held misconceptions and ascertain the leading causes of fuel degradation.
2. Do a comprehensive assessment of the condition of heating oil and storage tanks at end-use locations and measure the effects on performance caused by changes in fuel characteristics brought on by the use of fuel additives.
3. Identify and measure precursors to fuel performance problems.
4. Analyze fuel quality changes through the supply chain, and the heating season.
5. Analyze major factors, including additive programs, storage and maintenance programs, regional, and company practices that statistically impact end-use quality, and investigate alternative fuel storage systems.
6. Develop methods that will improve fuel quality and stability, develop specific tools and programs for improving fuel performance, and ultimately develop an industry-wide consistent set of practices that will reduce fuel related service calls.
7. Work with the NORA Education and Training Committee to educate the industry about our findings and prescriptions for improving fuel performance.

Background

This report focuses on No. 2 heating oil. It is a primary fuel for heating homes in the Northeast and Mid-Atlantic regions of the country.

The fuel oil supply and distribution network in the Northeast is highly efficient and very dynamic. In general, independent marketers provide the gateway for fuel oil supplies in New England. They own and operate oil storage terminals that receive supplies via tanker, barge or pipeline. They sell to retailers and to large bulk consumers from their terminal racks. Retailers sometimes transfer the oil to their bulk plant and from there dispatched in smaller trucks for home delivery. Many retailers, however, dispatch delivery-size trucks to the wholesale terminal, which then proceed directly to deliver the oil to homeowners. The entire delivery system in the Northeast has become tighter and tighter due to competitive pressures that require marketers to consolidate and deliver oil more efficiently. Nevertheless, the current system allows for great flexibility, which is imperative for maintaining adequate supply of oil at reasonable prices.

The Northeast gets its supplies of fuel oil from:

- Gulf Coast refineries (by pipelines, tankers or barges)
- Refineries in Philadelphia and New Jersey, and Mid-Atlantic (by pipelines, barges)
- Imports from foreign and offshore areas – Canada (by truck), Venezuela and Virgin Islands (by tanker)

Supplies of high-sulfur fuel rely about evenly on shipments from other regions, such as the Virgin Islands, and on local refineries. Virtually all products meeting the same specifications are commingled at distribution points. Due to the complex and dynamic nature of the fuel delivery network, the actual source of a batch of fuel is nearly impossible to determine. The movement of fuel makes it susceptible to contamination with water, dirt, other types of petroleum products. Without adequate inspection and quality control, the likelihood that fuel oil gets delivered to the end-user that does not meet specifications exists. When this proceeds undetected, fuel-related operational problems can occur.

Retail marketers and service companies indicate that fuel-related problems in customers' tanks occur far too often. Water as well as microbial contaminants gets into the system. The fuel at bulk terminals is typically much better than the fuel that eventually reaches the oil burner. While it is possible that off-specification oil is sold at a terminal, the majority of problems are in customers' tanks. It is far more common for newly delivered fuel to be contaminated by the old fuel in the tank, rather than the other way around.

There are many types of fuel performance problems. Given the extreme cost in terms of time, money, and consumer confidence, the Committee's initial focus is on problems that manifest themselves as no-heat calls caused by plugged nozzles, strainers, and filters. It appears that most of these problems are caused by a combination of thermal and storage instability, microbiological activity, bottom sediment, water, emulsions, and inorganics (dirt, rust, and fibers) in the fuel.

The vast majority of the fuel delivered to the customers is good. Most of our fuel problems that affect oil burners are created in the customer's tank and heating system, long after delivery. It is essential that technicians learn to identify what is causing the problems and to fix them. In the final analysis the most important people in the Oilheat Industry for ensuring Oilheat reliability are the technicians in the field, who keep our customers' systems operating at peak dependability, safety, and efficiency.

The NORA study has discovered that for some companies over 20% of the no heat calls are caused by fouling of the tank and piping system – indicated by clogged oil lines, clogged filters and sludge buildup.

A Work in Progress

This paper is only the beginning of a study on improving fuel performance of heating oil. This is a very complex subject with many variables. The NORA Fuel Performance Study has produced more questions than answers so far. However, the Fuel Performance Committee feels that we have learned several useful things, and we also need to solicit feedback from the Oilheat Industry. Therefore, we have written this update to tell you what we have learned, what we are

working on, and to ask for your help filling in the blanks. We hope to further the industry-wide dialog on this vital subject, and gather opinions on what we feel we have learned thus far. The more we all share what we are learning the faster we will reach workable solutions.

NORA's Fuel Performance Study

In October 2001 the NORA Fuel Performance Sub-Committee began extensive research with Brookhaven National Laboratory into fuel related service calls. Initial results indicate the following as potential problems. The first is the age of the oil tank. The population of oil tanks in the field is aging. We are not replacing tanks as fast as we installed them in the 1940's and 50's. As the tanks age, rust and sediment can buildup. The second factor is the age of the oil in the tank. It appears that oil breaks down over time. It has a shelf life. New high efficiency burners use oil more slowly, and firing rates have been reduced. This results in oil staying in the tank longer than it once did. The third problem is the volume and rate of delivery. Blasting oil into a tank too fast kicks up all the sediment and rust in the bottom of the tank. They are picked up in the oil lines and sucked into the filters and strainers plugging them, resulting in no heat. With this debris the industry's possible solutions are to not let the level of oil in the tank get too low, to slow down the pumping rate of the truck, and use diverters on the "blow or whistle pipes" (underground fill pipes) used to fill underground tanks. In some cases, the burner may need to be turned off whenever a delivery is made, and left off for two hours afterward to let the particulates settle before restarting the burner.

Major Elements of the Initial Study

- A detailed field assessment of fuel performance with a select group of Oilheat companies.
- A review of findings from other middle distillate users.
- Development of a sampling and analysis plan to evaluate fuel quality in the field.
- Field and Laboratory studies focusing upon improving fuel properties and fuel handling system design.

Activities to date

Industry Field Survey of Service Histories: The purpose is to establish a baseline of the magnitude of the fuel related service calls. Our researchers examined over 65,000 service histories in 9 selected Oilheat companies to determine the cause of fuel related service calls handled in January and February of 2002. The most significant finding from this study is that from 10 to 23% of unscheduled oil burner service calls are caused by fuel problems.

Review of Heating Fuel Performance R&D from other middle distillate users

Middle distillate fuels include heating oil, jet fuel, kerosene, and transportation diesel, which have the same boiling range and properties. Heating oil is used in many European countries, particularly in Germany and France. The NORA committee is studying the research done by other middle distillate users in the U.S. and Europe such as diesel engine manufacturers, emergency power generators, and the military. We are working with the ASTM Committee on Petroleum Products and Lubricants. We are also working closely with the U.S. military, especially the Navy, on fuel stability.

German research has been focused primarily upon improving specifications for heating oil. Their major areas of concern are low-temperature performance and thermal stability. There is considerable interest in the potential for condensing boilers in Europe and they have done a great deal of work on ultra-low sulfur fuel research. It appears that by 2005 two heating oils may be offered in Germany: regular at 2,000 ppm (.2%) and ultra-low sulfur at 50 ppm (.005%). IWO, the German organization equivalent to NORA, has published two manuals on background and guidance for fuel maintenance and storage that we are studying.

Field Sample Collection and Fuel Analysis: The objective is to evaluate the current condition of fuels from various sources, and identify any differences based on laboratory analysis and service history of those tanks from which the samples were taken. The samples are from four different companies, one with typical industry approaches to fuel performance, one that has aggressively pursued fuel performance improvement for ten years, one that buys oil from a pipeline close to refineries and treats the fuel, and one that is marketing low sulfur diesel fuel as heating oil including an additive package. A total of 65 samples were collected from bulk terminal tanks, barges, and customer's tanks. OCTEL Starreon's research lab performed most of the detailed analysis of the fuel samples. Fuels were also tested for storage stability at the Naval Research Lab, and filterability at Emcee Electronics.

Building BNL Capability to Test Fuels: After evaluating various stability test methods BNL purchased laboratory equipment to increase their ability to perform basic tests. They now have in-house capability to access heating fuel storage stability and correlate these measurements with service data.

Common Sources of Fuel Problems

Fuels that are transported, handled and stored many times throughout the distribution system are very much affected by the environment. Exposure to cold temperatures, heat, light, air and a variety of contaminants that are picked up along the way can degrade the quality of the fuel. Most of the fuel performance problems are caused by:

- Water in fuel systems can lead to rust, microbial growth.
- Heat causes the fuel to degrade faster (oxidation) forming gum and deposits; it degrades fuel color and increases metal corrosion.
- Cold temperatures can cause waxing and gelling of fuel which clogs filters and cause pump problems.
- Outside contaminants (rust, dirt, debris)
- Unstable fuel contains greater amounts of components that oxidize and polymerize forming gums, varnish, and sludge. During storage, heating oil can become unstable and begin to breakdown in as short a time as six months to a year.

Sludge that accumulates at the bottom of the tank is a combination of the fuel oxidation products and contaminants. In contact with water, fuel gums and deposits can form larger gel-like particles that are trapped by fuel filters. To prevent operational problems it is essential to have a good tank design, proper installation practices, and tank maintenance that allows for tank inspection, and withdrawal of water and sediment. Proper fuel filtration is necessary to ensure good burner operation.

Monitoring for potential problems in the delivery truck is critical in ensuring that you are not delivering contaminants, such as water or particles, to your customers' tanks.

Once fuel is delivered to customer's tanks, the effects from the tank environment on fuel quality and the effects of mixing with existing fuels already in the tank become very complex. Thermal and storage stability can degrade markedly in fuels in your customer's tanks. Many factors can cause fuels to degrade forming sediment and sludge. Water can provide a home for heavy infestations of bacteria, fungus, yeast, and mold that can cause fuel failures. Contaminates in tank bottoms does not necessarily lead to burner shut down. Other factors like the lack of adequate fuel filtration system, small nozzle size, piping configurations, high particulates suspended in the fuel, and the size and speed of oil delivery determine if the contamination will cause operational problems.

Fuel Stability

Heating oil is subject to a natural aging process, which can be influenced by heat, oxygen, and microorganisms, as well as metals and their oxides. Fuels tend to degrade with time and storage, and its effects are only compounded with added handling and transport because of the potential for contamination. If you start with an unstable fuel, it will not get better with time.

The stability of heating oil depends a great deal on the crude oil sources from which it was made, the severity of the refinery process, the use of additives and any additional refinery treatment. Normally, most heating oil have adequate stability properties to hold up to normal storage and distribution. However, fuels that are stored for long periods of time, and subjected to temperature extremes may form excessive amounts of sediment and gum that can plug filters, strainers, and nozzles. It is therefore necessary for us to consider a fuel's storage and thermal stability.

Storage stability should be assessed at the time of manufacture. There should be some stability performance criteria in the purchase specification. A test commonly used in stability specification is ASTM D 2274. It should be noted, however, that positive results from laboratory tests do not guarantee that you will have no operability problems in the field. All sorts of variables such as compatibility of fuels and tank conditions impact fuel stability. Nevertheless, adhering to some performance specifications assures a minimum level of protection.

Sulfur Content

In normal service, the efficiency of oil-fired appliances degrades over time as the heat exchanger surfaces become fouled. The rate of this efficiency degradation is about 2% a year. Most of the fouling is caused by sulfur in the fuel. According to Brookhaven tests changing to low sulfur fuel (0.05%) from typical heating fuel at (0.25%) could eliminate 80% of the sulfur dioxide emitted from the stack that is generated by residential heating systems.

Sulfur exists in varying amounts in all fossil fuels. The sulfur content of heating oil ranges from 0.05% to 0.5%, with No. 2 oil more typically at about 0.2%; the ASTM maximum is 0.5%. When burned the sulfur mixes with oxygen to form sulfur dioxide. It also creates a small amount of sulfur trioxide. The sulfur trioxide reacts with the water vapor in the combustion gasses to create sulfuric acid aerosol. As a gas it is not much of a problem for heating systems as long as the flue gas temperature stays high enough to prevent the steam and aerosol from condensing.

Problems occur when the steam does condense (at about 220 degrees F). Liquid sulfuric acid is very sticky. It adheres to the heat exchanger surfaces in a film and reacts with the iron in the heat exchanger wall. This creates iron sulfates, the white or rust colored crusty stuff we call scale. Scale makes up 50% of deposits on the heat exchanger. It downgrades efficiency by 1% to 4% over the year! It blocks flue passages restricting air flow and increasing smoke and soot.

Boiler tests at Brookhaven National Lab showed much cleaner boiler operation with low sulfur fuel (0.04%) as compared with typical heating oil at 0.35%. BNL did these tests with identical boilers located side by side for four months. The fuel containing the higher sulfur formed deposits at a rate 11 times greater.

The industry is working to lower the sulfur in heating oil. Many dealers are selling low sulfur diesel fuel as heating oil. To recognize the use of low sulfur diesel as heating oil the American Society for Testing and Materials developed ASTM D-396-01. It lists a specification for low sulfur No. 1 and No. 2 oils at a maximum 0.05% sulfur concentration. Scale and soot formation on heat exchanger surfaces are all but eliminated for properly tuned equipment. This means the efficiency does not degrade over the heating season, saving energy. It also results in decreased appliance service requirements. According to a NAOHSM study the average time between heat exchanger vacuuming is 21 months. Using low sulfur fuel we could extend this interval to 45 or 50 months!

We are finding other benefits to reduced sulfur fuel. Our initial tests indicate that low sulfur fuel (15 ppm) lowers the NOx emissions from oil-fired appliances. The refinery process that removes the sulfur also removes fuel bound nitrogen from the fuel. Obviously, using low sulfur fuel results in lower SOx emissions. It has better thermal stability than typical heating oil.

Color

Heating oil is normally the color of Champaign. To differentiate it from on-road diesel fuel for tax compliance reasons now all the heating fuel is dyed the color of cranberry juice. Some technicians suspected the dye of giving us problems, but extensive tests by RW Beckett and others have proven that the dye does not present any problems for oil burners. Problems with the fuel are not indicated by the richness of the color. However, if the fuel changes color rapidly, from light to dark, it could indicate contamination. By the way, fuel is very sensitive to light, and even top quality oil darkens quickly when exposed to light.

Detecting “Out of Spec” Oil

If your drivers do not catch a problem with the fuel they are picking up for delivery your first clue that fuel is not within ASTM specs might be a sudden rash of problems: plugged filters or strainers, delayed ignition, smoky fires, noisy flames, dirty fire and soot accumulation. If an analysis by a competent laboratory shows the oil to be out of spec, contact your supplier. You should replace the fuel. However if cold temperature operation is the problem, cold flow additives or blending with about 25% kerosene might be considered to improve flow.

Dilution and Blending

In some cases, when a fuel is below specifications, dilution with another batch of fresh fuel can effectively bring the entire batch within acceptable limits. For example, blending can lower a

high cloud point or raise the flash point. You should always do blending with a small test sample and analyze it before you attempt mixing the entire stock. Fuels that are contaminated with microbes, debris, or water should not be blended.

Excessive Pump Vacuum Conditions

Usually, the first sign of fuel performance problems is excessive vacuum readings at the fuel unit. To determine if vacuum readings are too high, compare the operating vacuum with the calculated vacuum. To calculate what the vacuum should be allow one inch of vacuum for every one foot of vertical lift, one inch for every ten feet of horizontal run, and an inch for a clean filter. If the actual operating vacuum is above the calculated vacuum something is restricting the flow. Possibly a valve is partially shut-off, the filter is plugged, a check valve or foot valve is sticking, or the oil suction line is kinked or restricted by sludge or ice. To clear the suction line use a hand pump to pump oil through the line. If this fails try running a small electrician snake through the line.

Tank Cleaning: Most problems that lead to no heat calls: plugged lines, filters and nozzles, are caused by sediment or sludge that slowly accumulates in the tank over a long time. If the material stays at the bottom of the tank, usually it does not cause problems. However, when the material is stirred up during an oil delivery the pump can suck it into the oil lines and cause problems. Chemical treatment alone will not cure a dirty tank. With massive accumulations at the bottom and on the sides of the tank, mechanical cleaning, fuel filtration, the use of additives and a preventative maintenance program are the only way to effectively remove the sludge. Some companies market portable tank cleaning and filtration systems that an oil company can use to do their own tank cleaning. The effectiveness depends a great deal upon the condition of the tank, access to the interior, and the operator's skill. Before attempting to clean the tank let the burner draw the oil down as low as possible to minimize the amount of fuel you will have to dispose of. Some dealers report limited success by removing all the material in the tank, washing down the tank sides and bottom with kerosene then removing it and filling the tank with a load of fresh kerosene.

There are companies that offer tank cleaning service. A BNL survey showed that typically, for a 275-gallon tank, cleaning costs range from \$125 to \$300. Some cover sludge removal; others have an added charge of disposing of the waste removed from the tank. Unfortunately, most dealers find that attempting to clean really bad tanks is a study in frustration. The most cost-effective thing to do would be to just replace it.

Tank Replacement: If the tank has excessive sludge, the only solution may be to replace the tank and oil lines. When you do install a new tank and lines, never pump the oil from the old tank into the new one. All you are doing is contaminating the new tank with all the bugs and wastes from the old tank. In short time the nice new tank can become as dirty as the old one was.

If you are installing (or maintaining) an outdoor, above ground tank we recommend you paint it a light color to reflect heat and thereby minimize moisture condensation inside the tank. There are several types of tank sheds available. They minimize water build-up and frozen lines. They extend tank life, and some offer containment.

Water Problems

Our worst problem is water in the oil tank. Water enters the tank in the following ways:

1. Condensation
2. Broken tank gauge (outside tank)
3. Loose fill or vent fittings and missing caps fill cap gaskets on some types of caps
4. Directly from delivery trucks
5. Leaking vent, fill pipes, or tank
6. When replacing an old tank with a new one and pumping the old oil into the new tank.

Sludge Happens

Since water is heavier than oil it settles to the bottom of the tank. In fuel systems containing water certain microorganisms can thrive. They feed off certain fractions of the fuel and can produce byproducts that lead to tank corrosion. Bacteria also generate sticky slime than can plug filters and strainers. This adds to the sludge. It is usually gray or black in color, and it is shiny like grease. Biological active sludge is corrosive, so rust flakes from the tank and other products of corrosion are also part of the sludge.

Sludge can build up in the bottom of tanks for years without causing too many problems. The two factors that cause it to become stirred up and suspended in the fuel are low tank levels and fast deliveries. It sticks to the walls of fuel lines, pitting them and plugging them. It plugs filters, strainers, and nozzles.

Bacteria thrive where there is water. Make it a habit of checking tanks for water whenever you go on a tune up or service call. If water is present, remove it and find out where the water came from. Alert management and seek advice. Once you have removed the water you should try to clean the sludge from the tank and, if necessary, treat the tank with a registered (EPA) biocides to kill the bacteria. In some cases the sludge build up is so great you are better off just replacing the tank.

Tank –Piping Configuration

Most residential tanks offered in Germany have double walls for leak protection with a noncorrodible inner tank. As such, the fuel supply line enters the tank from the top and has either an intake 2-4 inches off the bottom of the tank, or a floating suction intake. In Canada and the United States, steel tanks, which are most commonly installed, are manufactured with a standard opening at the bottom for the fuel supply to the burner. This is to prevent water that condenses in tanks from building up. Oil burners will tolerate a little water in the oil. If we burn up the water as it condenses by pulling off the bottom, it will not have a chance to build up and allow sludge to form. So during a tank installation always pitch the tank slightly to the suction end, and draw off the bottom of the tank.

Obviously, the exception to this rule is outdoor above ground tanks. In cold weather the water will freeze in the suction line with bottom suction and you will have no heat. It appears that the best solution to this problem is to run the suction line into one of the top tappings on the above ground tank, use a floating suction line device, and occasionally remove the water that condenses in the bottom of the tank.

Nozzle Coking

If you suffer an operating failure and you find that the filter and strainer are clean but the nozzle is plugged with coke (a dull black substance), check the installation. You may not have enough draft, or excessive heat reflecting back from an old brick chamber on the nozzle after shut down, nozzle after-drip, or a draw assembly and end cone sticking into the chamber. We have good mechanical fixes for these problems: post purge, draft inducers, interrupted ignition, cerafelt chamber liners, and end cone amulets to name a few.

If you encounter nozzle coking, find out what is causing the nozzle to get hot. The problem is most likely to occur after burner shutdown. Check the over fire draft after shutdown. Check to see if draft regulator closes after shutdown. If it sticks open it will reduce draft over the fire needed to cool the nozzle. Check electrode settings, and the type of chamber. Check to be sure the end-cone is flush or slightly recessed from chamber face. Check for after-drip. Any of these problems could be the cause of coking.

Low Temperature Performance

The behavior of cold heating oil is particularly important during its transportation and storage. As oil gets cold several bad things happen. First, any water in the fuel freezes, plugging lines and filters. Second, the viscosity of the oil begins to increase causing burner operation problems. Third, wax crystals begin to form in the oil. Paraffins (long-chained hydrocarbons) are a natural component of heating oil. They burn very well, however, below a certain temperature they precipitate out of the fuel as a white haze or in flakes similar to snow flakes. These crystals can plug lines, and filters. The diesel fuel industry has developed a number of tests for flow and filterability that are helpful.

- In the heating oil specification, ASTM D396, we define low temperature operability as pour point. The pour point is the lowest temperature at which the fuel flows, and is determined under lab conditions. In the field this is not very useful, as the fuel has already clogged the filter and strainer at temperatures way above the pour point.
- The Cloud Point (ASTM D2500) is the temperature at which wax crystals grow large enough to become visible as a cloudy haze. This usually occurs at about 15 degrees F.
- The Cold Filter Plugging Point, CFPP, (ASTM D 6371) is considered the best test for diesel engine operation. In Europe and Asia CFPP is used to define low temperature operability for heating oil.

Oil temperature is the main factor in changing oil viscosity. As the temperature of the oil goes down the viscosity goes up. As the viscosity of the fuel flowing through a nozzle increases, so does the flow rate. The oil is atomized into bigger droplets and this may result in increased smoke and soot.

The easiest way to counter the effects of cold oil is to increase pump pressures. This decreases droplet size and better defines the spray angle that makes burners less susceptible to high viscosity oil. Remember increasing the pressure also increases the flow rate, so size the nozzle correctly. Another way to solve this problem is to install a nozzle line heater. This simple strap

on device increases the temperature of the oil arriving at the nozzle to about 100 to 120 degrees F.

How to Deal With “Frozen” Tanks and Oil Lines

Cold-flow additives can help avoid this problem but once the oil in the tank or in lines has wax, or water in the bottom of the tank is frozen, it is too late. The best solution to this problem is to top off the tank with kerosene. The agitation of the fuel in the tank caused by the kerosene delivery and the solvency of kerosene break up and dissolve the wax crystals. You may also have to remove the filter, temporally convert to a one-pipe system and heat the suction line with a hair dryer or heat lamp. If you are unable to arrange for a delivery, some technicians report that adding as little as five gallons of kerosene can help. Others report having success “shocking” the tank with a solvent such as denatured alcohol or pour point depressant. Be careful with alcohol. It will lower the flash point of the fuel. One experienced serviceman suggests building a temporary shelter for the tank out of plywood or cardboard, whatever was at hand, then use a heat lamp and hair dryer to warm up the lines enough to get the oil to flow. Be very careful with heat tapes. It is not a great idea, but a fairly common practice for homeowners to put heat tapes on the oil lines. If you wrap a heat tape over itself it can burn through its own insulation causing a short that can result in a fire. The insulation on the wires can also crack with age and exposure to the elements creating potential for a fire.

Quick Tests for Fuel Quality

Clear and Bright Test

The purpose of this easy test is to detect possible water or solid contaminants in the fuel by visual inspection. This is usually done when a bulk load of fuel is received. The fuel can be drawn from any barge, tanker truck or small delivery truck where there is access for a manual or bottle sampler. Using a clear glass container, such as a mason jar, to visually observe the fuel for a “clear and bright” condition. Let the sample settle for a minute to remove the air bubbles. Observe the sample against a light background for a clear bright condition. The sample should look more like cranberry juice than red wine. Swirl the container to create a whirlpool. Free water and solids tend to collect at the bottom of the whirlpool. The container must be thoroughly cleaned before testing. The term “clear and bright” does not refer to color. Clear and bright fuel has no floating or suspended matter, and no free water. Bright fuel tends to sparkle.

Visual Detection of Microbial Contamination (*bugs*)

The Clear and Bright can also be used for testing tank bottoms, filter cans, and fuel pump draining for the presence of microorganisms, which we can see and smell. Put the fuel to be tested into a clean white bucket or clear glass jar. Allow the sample to settle for two minutes. Tip or swirl the container from side to side, looking for any evidence of dark colored solids, dark colored water, substances that cling to the side of the container, or mucus like material. Carefully pour off any clear fuel and collect a sample of the suspect material in a clear glass jar. Backlight the sample and closely examine it. If it is mostly solids check to be sure it is not rust. This can be done by holding a small magnet, a magnetic tank patch is perfect, against the side of the sample bottle and moving it around. Rust particles will collect and follow the magnet. If the sample is discolored liquid, to check for rust run it through some white filter paper. Let the captured sediment dry, then if it responds to your magnet, it is rust. If the sample is a dark colored sludge

like material and it does not respond to the magnet, then it is probably microbial contamination. Other indicators of these microorganisms are a matty, lumpy, or stringy consistency and a rank moldy odor.

Water Detection Paste

Water detection pastes are used to determine the depth of water at the bottom of the storage tank. It will not detect water that is suspended or dissolved in fuels. Apply the paste in a thin coating on a gauge stick from zero up to a couple inches above the suspected oil water interface. Carefully lower the stick into the tank until it lightly touches bottom. Hold it in this position for a minute or two. Remove the stick and observe the color difference on the paste. The paste will change color if it contacts water. The water level will be clearly indicated by a definite color change where water contacts the paste.

Recommended Time Schedule for Sampling and Analysis

- In a static tank commonly used for bulk storage, you should conduct both bottom and bulk sampling at least twice a year. You should check for water accumulation in the tank every 90 days.
- You should check customers' tanks for water once a year, and then drain off the water if detected.
- You should take random samples of incoming fuel and send it to a lab for testing to ensure that the fuel comes up to your specifications. Doing a quick visual test on every load can help you avoid buying problems.

Recommendations

What gets measured gets fixed

Maintaining a strong quality control program allows you to deliver fuel to your customers that meets specifications, and minimizes fuel related service calls. The most practical way of measuring fuel quality and the effectiveness of your fuel treatment program is to establish a record of your customers' service histories. By recording such information as the total number of service calls during the heating season, the number of gallons sold, the type of service needed, the type of fuel storage system, and the cost of the call you can evaluate your progress. You should build a way to quickly identify problem tanks into your system. Your goal should be to identify a tank that needs attention on the second call, not the fifth.

Oil Filtration

We strongly recommend the installation of filters in oil burner fuel suction lines to protect the pump and nozzle by trapping contaminants before they reach these components. There are passages in the oil burner nozzle that are smaller than the diameter of a human hair. It takes very little contamination to plug up these passages in the nozzle. This is why it is critical that we do everything we can to be sure we are delivering clean oil to the nozzle. Our primary emphasis when installing and servicing oil burners must be reliable operation.

The best way to ensure reliable clean oil is delivered to the nozzle is by installing a quality oil filter on every oil burner you service. There are a wide variety of filters available, but they all fall

into one of two categories: spin on filters and cartridge type filters. The spin on filters are similar to the oil filter on your car. The filter container, or can, and filter element (resin coated filter paper with large surface area folded into a filter housing) are all one piece. The cartridge type has a replaceable filter element cartridge that you place into a filter can that attaches to the filter head. Most burner pumps contain a 100-micron mesh strainer. Nozzles also have a mesh or sintered bronze filter. For nozzles up to about 1.35 gph firing rates the nozzle filter is typically made of sintered bronze nominally rated for filtration to 40 microns. The tangential metering slots in the nozzle are typically 60 to 90 microns. This is why we must be very careful handling nozzles to avoid allowing the dirt or grease from our fingers to plug the nozzle.

A filter is a porous substance through which oil is passed in order to remove, or strain out solid particles and impurities that could block the flow of oil. Filters can be made from a variety of materials including: wool felt, wound yarn, sintered plastic, continuous micro-spun fiber, resin-coated paper, and stainless steel mesh. Filters are sized by flow rate (GPH) and pressure drop (inches mercury HG). Each filter also has a micron, or mesh rating. These ratings represent the amount of pressure drop or degree of filtration capability. A lower micron (higher mesh) rating indicates a tighter filter construction, able to remove finer particles. Filter elements made from sintered plastics rated 30-75 microns, spin on filters with resin-coated paper or rayon filters rated for 10-micron, are commonly used. Felt and wound yarn filters are also popular.

Manufacturers are now selling a double filtration nozzle for mobile home installations and other units with very low firing rates. In addition to the standard nozzle filter these nozzles have a secondary internal filter located immediately before the metering slots. This extra filter gives the nozzle 35% more nozzle filtration. The internal filter does not change the nozzle's performance. It just increases its longevity of service.

Many service managers are now advocating the installation of two fuel filters on problem installations. They install a standard cartridge by-pass filter at the tank and a 10-micron no-by-pass spin-on filter at the burner.

Fuel Additive Treatment

More and more dealers are chemically treating heating oil in the hopes of providing greater stability, improved dispersion, and controlling biological growth. Additives are designed to prevent or retard fuel deterioration. Numerous types of additives are available on the market, but reliable information on their proper use and effectiveness is limited. A successful fuel treatment program requires knowledge of the quality of the fuel in the tank and the specific service problems. Just using an additive off the shelf without testing can sometimes be more harmful than doing nothing. Additives are fuel specific. They may interact differently with different fuels. A general misconception is that a single ingredient can effectively cure problems associated with fuel degradation. If the fuel has already deteriorated, treatment with an additive will not restore fuel quality. For example, a dispersant cannot breakup large masses of sludge. A treatment program is most effective when used with clean, fresh fuel in a clean storage system. Correct, consistent dosage of the additive is important. We have a great deal more we must learn about additives before we can make too many specific recommendations.

The key to effective additive treatment is to understand the following points:

- What the additive is used for
- Treatment rate and effectiveness
- The limitations
- Costs
- Hazards and safety precautions
- Regulations on the usage, storage, and disposal of the additive.

Selection of Additives: The multifunctional aftermarket additives available for heating oil are proprietary products that offer a range of properties. Additive suppliers do not advertise the specific chemicals in their packaged products. This makes it difficult to evaluate the effectiveness of additives, and to compare different products. NORA is working on developing a test program to evaluate these products. Because of all the variables involved it is a difficult task. Meanwhile, your best bet is to deal with reputable sources that can supply you with references from satisfied customers. We hope the following list of general guidelines and questions will help you in your quest for the right additive package for your situation.

- Define the problem and the additive that is needed.
- Make sure the fuel sample being tested represents the fuel being treated.
- Will the additive be used once, or is continuous treatment required?
- Does the additive perform more than one function?
- Does the additive supplier have technical support if there are questions or problems?
- Can the supplier provide a way to determine effectiveness in specific cases?
- Follow all safety and handling instructions on the labels and Material Safety Data Sheets that should accompany the package.
- Follow the recommended treatment rates.
- Properly dispose of the additive containers. Know and follow the local laws concerning disposal of sludge and water bottoms.

Preventative Maintenance

You should base your preventative maintenance program on need, resources, and common sense. A successful fuel quality surveillance program must include the following:

1. Specifications when purchasing fuel
2. Monitoring, sampling, and record-keeping
3. Good housekeeping

Good housekeeping means doing everything you can to minimize dirt and water from entering tanks. As we have discussed, water promotes the growth of microbes, which use the fuel as a food source, and accelerate the growth of sludge and internal corrosion of the tank.

Sloppy procedures or a lack of any procedures can be costly. All personnel who are involved with fuel delivery and storage as well as all technicians should be trained and motivated on why careful housekeeping and maintenance are so important. The following are some recommended steps you should incorporate into your program.

- Before removing the fill cap for a buried tank, the driver must be sure water, dirt, snow or ice cannot fall into the tank. After delivery, drivers should check gaskets and o-rings if needed on the fill cap to be sure they are in good shape, reinstall the fill cap, and make certain it is sealed tight.
- While making a delivery the driver should check to be sure the vent cap is in place, there is no water around the fill, the vent pipe is solid, there is no water in tank, the legs are stable on a solid foundation, there are no signs of rust, weeps, wet spots, deep scratches, or dents on the tank surface, no oil leaks, or signs of spills, and check to see if the tank needs painting.
- Sampling of tank bottoms should be done routinely (during the tune-up) for cleanliness and lack of water.
- If excessive sludge and water are found they should be removed as soon as possible.
- Hold up on deliveries to problem tanks until the sludge and water problem is rectified.
- Once the sludge and water are removed from the tank: fill the tank with kerosene or specially additized fuel, tune-up the burner, hand-pump the oil lines thoroughly, replace the filter, strainer, and nozzle. Schedule a follow-up call a month later to see to it that the tank and lines remain clean.
- The tank's fill boxes, fill pipes, and vent caps and pipes, and remote fills should be checked on every delivery and tune-up for cracks and leaks. Often the problem is a hole in the vent pipe just below ground level. Dig a few inches of soil away from the vent to check for rusting. If the fill box is in a driveway, it should have a "mushroom-type" fill box with a watertight gasket rather than a metal to metal fit.
- When additives are used, they should be added before filling the tank, if possible, to facilitate proper mixing.

Conclusions Thus Far

How to decrease fuel related service calls remains NORA's #1 R&D Priority. We still do not know enough. Until our NORA study is done, here are some strategies that seem to help, however, we need to learn more.

- Curing fuel performance problems requires a coordinated effort in four areas. These four are interrelated. Problems can develop at all levels and can compound one another in unexpected ways.
 1. Fuel quality issues from suppliers – Are additives used? Are tighter specifications for heating oil needed? What are the sulfur levels in the fuel? What type of housekeeping is done during storage and transportation?
 2. Any additization at dealer's bulk plants and end users tanks
 3. Tank and fuel handling system installation practices
 4. Tank and fuel handling system monitoring and maintenance
- Our field analysis indicates that some companies seem to be purchasing more consistent fuels than others. Low sulfur diesel fuel and heating oil from pipeline sources appear to be more stable than barged heating fuels.
- Most of the fuels supplied to oil dealers have acceptable thermal stability.
- We may need to establish stability criteria for heating oil to ensure product integrity at the consumer's tank.

- Quality control or spot checks of the fuel you buy is a worthwhile effort to ensure product meets specifications and cleanliness.
- An unstable fuel is a key factor in contributing to sediment formation in the tank. Fuels are degraded as they are transported and stored downstream from the refinery.
- We are now evaluating any potential benefits of aftermarket fuel additives to stabilize fuels and minimize gums.
- Contamination in the customers' tanks is the leading cause of sediment and sludge buildup, filter plugging, and burner shut down. If you start with a fuel that is prone to degradation, then contamination in your customers' tanks will make it worse.
- Storage stability of fuel should be considered especially if it is expected that the oil tank will have low turnover and fuel is stored for extended periods (longer than 6 months-1 year). Keep storage tanks and delivery trucks clean, and keep the water bottoms to a minimum. Filter the fuel you deliver.
- We must improve our data base management systems so we may easily track the number of service calls caused by fuel problems. This will help us pin point problem tanks, and allow us to do cost-benefit analysis of any changes we make to additive treatment, fuel supplier changes, filtration strategies, and other fuel performance initiatives we may undertake. Count and report the number of fuel related service calls. This will help us to realize the magnitude of fuel problems. It will also help you identify your customer's problem tanks so you can clean or replace the tank before you make too many wasted service calls replacing nozzles and filters.
- Water is a major culprit associated with service problems that we can easily remedy by routine monitoring and removal if present. The water supports microbiological growth, which can lead to massive buildup of slimy, stringy mats that clog filters and produce corrosive by-products. This further leads to internal tank corrosion and odor problems. The accumulation of sludge in end users' tanks and associated service problems exist for all companies to varying degrees. Current storage practices that do not include routine water and sediment removal contribute to the fuel degradation process that will inevitably lead to excessive sludge buildup. Water monitoring should be incorporated into routine heating system maintenance and service calls. Any water removal or fuel performance problems should be noted in the service database to enable you to more effectively track "problem tanks" making diagnosis and resolution of chronic problems easier. We also need better tank design and installation practices for easier collection and detection of water and sediment at the low point of the tank. We can then do water and sediment removal more effectively.
- Topping off oil tanks, especially outdoor above ground tanks in the spring is a good idea. The less air in tank, the less condensation will appear. The down side to this practice is the oil will sit in the hot sun all summer. This could cause unstable fuels to begin to form particulate. This might be the reason why we seem to suffer more fuel related problems in the fall. In an upcoming study we will assess whether additives can help with stabilizing the fuel.
- Install quality filters on all your customer's tanks. With problem jobs you may want to install a double-filter system, a combination coarse filter at the tank, and a fine filter at the burner.
- If there is a problem with nozzle coking it may be due to extremely high temperatures on the surface. Try keeping the nozzle cool by improving draft with a draft inducer, installing post purge and a cerafelt liner for the chamber, fix the after-drip, and recess end cone 1/4".

- A well-defined field test is needed to measure the effects of chemical additives in a program of preventive maintenance and fuel performance. Stabilizer additives should first be tested in the lab to be sure the potential improvements actually happen.
- Reducing sulfur in fuels reduces the amount of sulfuric acid in the combustion products. This can lead to less scale build up on the heat exchanger. In the refining processes to remove sulfur other reactive compounds containing nitrogen are also eliminated, thereby improving the fuel's stability.

Acknowledgments

Acknowledgements must begin with the NORA Board of Directors and the NORA Executive Committee for initial funding of this project. We also thank the National Oilheat Research Institute, NORI, for their continued support of this on-going initiative. Special thanks go to Tom Santa and Don Allen. Without their vision and commitment this study and report never would have happened.

The NORA Fuel Performance Sub-Committee has done most of the heavy lifting on this project. We thank them for all their time and expertise they have shared with us to make this program a success. The following people make up the committee.

Tom Santa (Santa Energy) Chairman	Wai-Lin Litzke (BNL) Project Manager
Don Allen (ET Lawson)	Dr. Christian Kuechen (IWO)
David Bates (Hoffman)	Tim Laughlin, P.E. (NC Petroleum Marketers)
John Batey (NORA & OMA)	Lindy Lindveit (Westwood)
Dr. Tom Butcher (BNL)	Roger McDonald (BNL)
Dr. Dave Daniels (OCTEL Starreon)	Rich Mohrfeld
Bill Davenport (Heritagenergy)	Rosaire St-Pierre (Granby Tanks)
Dr. Jim Evans (Motiva)	Vic Turk (RW Beckett)
Bob Hedden (NORA & OMA)	John Wilcox (Moyer)
Chris Keyser (Owner Services)	Doug Woosnam (SICO)

We appreciate the help from Dan Gianfalla (ConocoPhillips) in obtaining test fuels for our study.

Paper No. 06-03
Benefits and Advantages of Marketing Low Sulfur Heating Oil Including
Results from a New York State Low Sulfur Market Demonstration

Roger J. McDonald
Brookhaven National Laboratory
Building 526
12 North Six Street
Upton, NY 11973
Phone: 631-344-4197
Fax: 631-344-2359
E-mail: mcdonald@bnl.gov
Internet: www.bnl.gov

and

John Batey, PE
Energy Research Center, Inc.
35 Fawn Rd.
Easton, CT 06612
(203) 459-0353
E-mail: erc@optonline.net

Funded jointly by:
United States Department of Energy
National Oilheat Research Alliance
NYS Energy Research & Development Authority

Benefits and Advantages of Marketing Low Sulfur Heating Oil Including Results from a New York State Low Sulfur Market Demonstration

Roger J. McDonald, Brookhaven National Laboratory and
John E. Batey, Energy Research Center Inc.

1.0 Introduction

This paper combines a discussion of the benefits and advantages of marketing low sulfur (0.05% by weight) heating oil with recent results obtained in New York State, where this fuel has been marketed to over 1000 customers for the last three years. It contains a summary of findings discussed in an interim report for an ongoing project sponsored by the United States Department of Energy (DOE) and the National Oilheat Research Alliance (NORA). The results discussed in the interim DOE/NORA report document the advantages of marketing low sulfur heating oil. The report summarizes over ten years of research into the subject including work conducted at Brookhaven National Laboratory (BNL), CANMET Energy Technology Centre in Canada, the United States Environmental Protection Agency (EPA), the National Association of Oil Heat Service Managers (NAOHSM) and the New York State Energy Research and Development Authority (NYSERDA). It clearly lays out the case for the many advantages associated with the marketing of low sulfur content fuel including, environmental benefits, maintenance reduction advantages and business advantages. Results from the field study are included as experience has been gained by several companies including a New York State marketer who has been delivering this fuel to over a 1000 customers for the last three years. The field evaluation project is a joint effort conducted by Energy Research Center Inc. (ERC) and BNL and is sponsored by NYSERDA.

2.0 Background

In the years leading up to 1991 when the heating oil industry first started to have the opportunity to seek out low sulfur fuel for their customers for the very first time, researchers at BNL had already been working for several years on the question of sulfur content and its impact on heating equipment and efficiency. The presence of sulfur in the fuel contributes to the corrosive nature of the products of combustion which is a major contributor to the fouling of heat exchangers in boilers and furnaces. The build up of fouling deposits contribute to a slow degrading of system efficiency over time and is costly in terms of the time and effort of the service technician's effort to remove them.

The EPA in 1991 mandated that on highway diesel fuel be limited to 0.05 percent sulfur by weight to reduce tailpipe emissions. Prior to this time, light distillate used for heating oil and diesel engines had very similar physical and chemical properties and were at times co-mingled in the same bulk storage tank. The new low sulfur highway diesel provided both a reason to study the potential benefits (or detriments) of using this low sulfur content fuel as a substitute for higher sulfur content heating fuel in residential oilheat systems. This led to a series of experiments that resulted in a great deal of knowledge on the subject. BNL ran experiments to determine the nature of the fouling process, the role sulfur plays, and the benefits of reducing sulfur content of ASTM No.2 heating oil. BNL also analyzed the environmental benefits of

reducing sulfur and the associated reduction of emissions of sulfur dioxide into the environment. BNL conducted initial studies in employee homes on Long Island, NY to fully understand the role of sulfur on the fouling process over an entire heating season under real operating conditions. Inquires were sent to the manufacturers of oil pumps to answer the important issue of pump wear and lubricity. There were no reported concerns with the use of low sulfur oil at the 0.05% (500 ppm) sulfur level. Laboratory studies at BNL were supplemented by additional studies at the CANMET Energy Technology Centre in Canada sponsored by the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) which had excellent correlation to the results obtained at BNL. There were many benefits to be realized and no down side to burning low sulfur (0.05% by weight) fuel. One marketer, E.T. Lawson in Hampton, Virginia felt so strongly that marketing low sulfur fuel had merit that they began marketing it as a premium heating fuel starting in 1993 and has been supplying it ever since. E.T. Lawson sells under the product label “Ultra.” The Ultra product has been a success for nearly ten years and this marketer who now only sells his customers this premium fuel. This paper will present the case for this superior fuel for the oilheat marketplace.

3.0 Air Emissions Reduction

3.1 Sulfur Oxide Emissions

The sulfur in any fuel results in sulfur dioxide being released into the atmosphere when it is burned. During combustion in residential heating systems, roughly 99% of the sulfur in the fuel is oxidized to form sulfur dioxide (SO_2) and emitted from the stack. The remaining 1 percent of the fuel sulfur is converted to sulfur trioxide (SO_3) in the flame. Changing to low sulfur content fuel (0.05%) could eliminate roughly 75 to 80 percent of the sulfur dioxide generated by residential oil heating systems. In volunteering to market a lower sulfur fuel, heating oil dealers can make a substantial contribution to helping preserve the clean air that we all breathe. Although this result requires knowledge of combustion science, there are numerous studies that can also be cited to provide evidence. This was reinforced most recently in a recent paper (Ref 1) reported by S. Win Lee, Ph.D., of the CANMET Energy Technology Center-Ottawa, Natural Resources Canada as reported at the 2002 NORA Technology Symposium. Figure 1 is a plot of SO_2 emission rates for fuel oils of various sulfur contents from 0.05 percent (500 ppm) up to 0.6 percent (6000 ppm). This illustrates the linear relationship between sulfur content in the fuel and

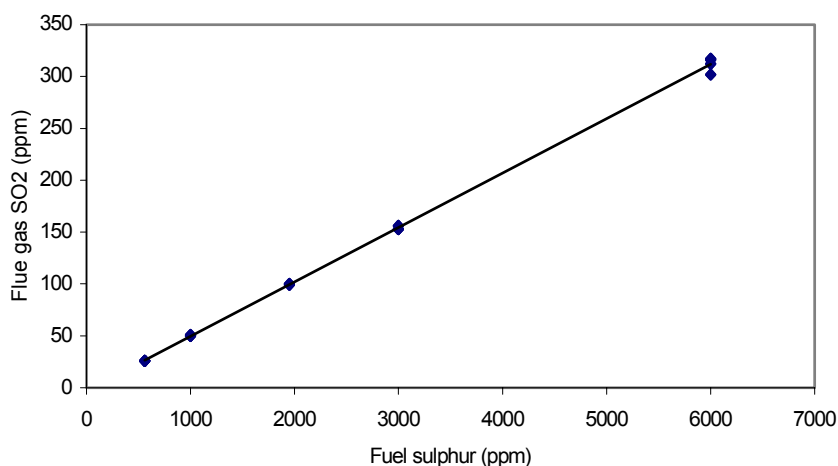


Figure 1 Effect of fuel sulfur on flue gas SO_2 emissions

SO₂ emission rate resulting from combustion of the fuel. This confirms the analytical results obtained by BNL based on calculations related to the fuel composition and knowledge of combustion science.

Currently in the U.S., heating oil for residential use has an average sulfur content of about 0.20-0.25 percent (%). The ASTM limit for No. 2 heating oil is 0.5 % sulfur by weight. Considerably higher levels have been allowed, however, and regulations vary by state and area. Low sulfur fuel, 0.05 % by weight, is now mandated for use in highway diesel engines as an emissions control measure. Recently ASTM approved an additional Low Sulfur No.2 Heating Oil specification. The Oilheat Manufacturers Association in November 2001 recommended its use as a fuel of choice when possible to improve air quality and reduce equipment maintenance requirements.

More recently, on April 30, 2003 the NORA Board of Directors passed a resolution (during the report on the National Oilheat Research Institute) that stated; ***“Resolved: That the National Oilheat Research Alliance endorses the use of low sulfur Oilheat in residential and commercial combustion. That NORA publicize the advantages of this fuel to the industry participants, and prepare communications tools and information that will be valuable to customers in their decision making. That the goal of the National Oilheat Research Alliance shall be that 80 percent of the fuel consumed as heating oil shall contain not more than 500 ppm sulfur by 2007.”*** This is a major commitment on the part of the oilheat marketers of the United States that will benefit not only oilheat consumers but all Americans with regard to the environment as documented in this paper.

3.2 Particulate Emissions

Particulates in the ambient air are an important pollutant concern. These tiny particles can cause lung disease, cancer, and premature death. Sources of fine particulates in the atmosphere include power plants, vehicles, road dust, and industrial processes. Particulates from oil-fired heating systems can be considered as two major parts, solid particulates and condensable particulates. The solid particulates include soot emitted directly from the boiler and this is composed of unburned carbon particles and any ash residue in the fuel. The condensable particulates are not actually particles when the combustion products leave the boiler or furnace but vapors which condense into particulates when the exhaust gas cools after leaving the vent and mixing with cool ambient air. These condensable particulates include some hydrocarbons but the major part is sulfates formed from a tiny fraction of the sulfur in the fuel.

For large stationary pollutant sources, such as power plants, the traditional method of measuring particulate emissions involves drawing an undiluted sample of the flue gas through a hot filter. This basically measures the solid particulates but not the condensable particulates. EPA Method 5 defines this in detail and this is the basis for particulate emission regulation. It is also the basis for particulate emission factors assigned to stationary sources in AP 42 – a compilation of standard emission factors. There is growing recognition, however, that the condensable particulates are very important for health and there is now great interest in measuring these using sampling systems which simulate what happens after the exhaust leaves the vent. These sampling systems have a controlled cooling / dilution section prior to sampling on a cooler filter. For engine applications dilution sampling has long been used as the measurement standard.

Combustion sources emit particulates with a range of sizes. Health effects are most strongly associated with the smallest particles – those under 2.5 microns (2.5 millionths of a meter), roughly 1/30th the diameter of a human hair. For many power plants some fraction of the total particulates are in this “fine particulates” category. Condensable particulates are all fine particulates. For oil-fired residential boilers and furnaces all particulate, both solid and condensable, are under 2.5 microns.

For diesel engines, a large fraction of the particulate emissions (solid + condensable) are sulfates, derived from the sulfur in the fuel. This situation has been a key driver in the recent reductions in allowable diesel fuel sulfur content. The situation is similar in oil-fired heating appliances where, for a typical fuel sulfur content, the composition of emitted particulate matter is roughly: 23 % filterable and 77 % condensable (Ref 2). The condensable particulate matter is largely sulfates. Based on this it would be expected that the particulate emissions from oil burners are a strong function of the fuel sulfur content.

3.2.1 CANMET Particulate Measurements

Figure 2 shows the results of recent measurements made at the CANMET Energy Technology Center with fuels with a range of sulfur content. This clearly shows the impact which fuel sulfur has on total particulates (Ref 1). A shift from ASTM No.2 fuel with 0.2% sulfur to a fuel with 0.05 percent sulfur translates to a reduction of about 80 percent in particulate matter.

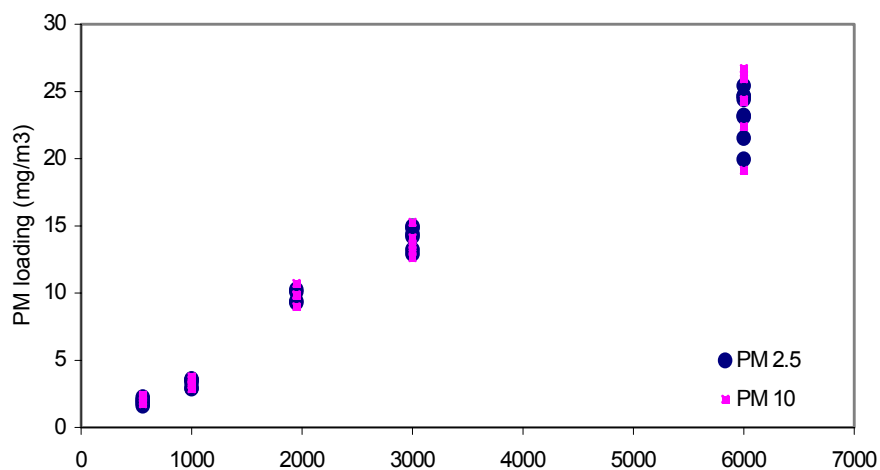


Figure 2 Effect of fuel sulfur on PM_{2.5} and PM₁₀ emissions

3.3.2 EPA Standards

Dr. S. Win Lee (Ref 1) reported that “The U.S. Environmental Protection Agency (USEPA) promulgated revised National Ambient Air Quality Standards (NAAQS) for ozone and particulate matter in 1997 to address ambient concentrations of very fine PM. The particles with an aerodynamic diameter less than 2.5 μm , commonly known as PM_{2.5}, are introduced to the standards based on the reported concerns over human health effects associated with these respirable substances. Several studies have shown associations between fine PM concentrations and adverse health effects including increased mortality and cardiopulmonary and cardiovascular illnesses in most susceptible people although only a few key reports are referenced here. The

effect of ambient fine PM on the visibility degradation has also been widely reported in industrialized countries. Similar regulatory considerations are given in Europe with the World Health Organization's acknowledgment of the evidence of associations between PM concentrations and adverse effects on human health at low levels of exposure commonly encountered in developed countries. The Office of Air and Radiation of the EPA reported the U.S. implementation timeline for PM standards in 2000, as shown in Table 1."

Table 1. The US implementation timeline for PM standards

1997	EPA issues Final PM _{2.5} NAAQS
1998-2000	Ambient PM monitors put in place nationwide
1999-2003	Collect monitoring data
2002	EPA completes 5-year scientific review of standards
2003-2005	EPA designates non-attainment areas
2005-2008	States submit implementation plans for meeting the standard
2012-2017	States have up to 10 years to meet the standards plus one year extensions

Even though the EPA has not finished its studies, it is very likely if not guaranteed that New England and East Coast States, which is the heart of oilheat marketplace, will be designated as non-attainment areas. This has been the case in most prior EPA designations of this nature. The oilheat community can get ahead of the curve by voluntarily shifting to low sulfur fuel and dramatically reducing the potential for negative publicity in this area. In fact, the oilheat industry has a unique opportunity to become a leader in this environmental area.

3.3 Nitrogen Oxides

All petroleum crude stocks contain varying small amounts of non-hydrocarbon materials or impurities, and the more important of these (at least from the emissions standpoint) are nitrogen- and sulfur-bearing compounds. The hydro-treating processes that are used to reduce sulfur during refining also reduce nitrogen by a similar mechanism. Although the two reactions have different rates and the effects are independent because nitrogen and sulfur are present independent of each other in different refinery stocks, the general rule is that by reducing sulfur content the nitrogen content of the fuel is reduced as well. Typical sulfur and nitrogen contents in common petroleum-based fuels are shown in Table 2.

Table 2 Typical Sulfur and Nitrogen contents in Petroleum Fuels

(all values, ppm)	<u>S-Nom</u>	<u>N-Nom</u>	<u>S-Range</u>	<u>N-Range</u>
Hi-Way Diesel (Gr. 2-D low sulfur)	360	150	< 500	100-200
Off Road Diesel (Gr. 2-D diesel)	3260	350	2000-5000	200-500
Heating Oil (Gr. 2 fuel oil)	1700	650	1000-3000	< 900

Work reported by Victor Turk, Director of Engineering of the R.W. Beckett Corporation (Ref 3) evaluated the effect of reduced sulfur / nitrogen fuels in three burner designs, and showed important reductions in NO_x formation. The reductions shown in Figure 3 show the cumulative effects of both fuel and burner effects. These fuel-related reductions were similar from burner to burner, with the low sulfur fuel reducing NO_x 5-10% compared to the standard fuel, and the ultra low sulfur fuel reducing NO_x by 20-30% compared to the standard fuel.

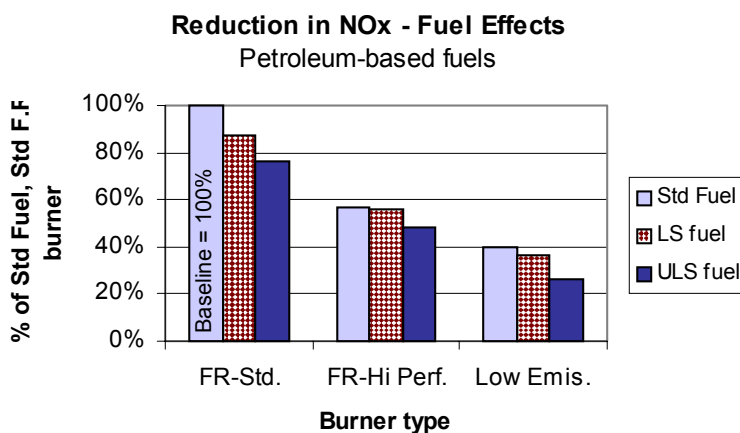


Figure 3 Fuel sulfur effects on NO_x formation

4.0 Fuel Stability and Sulfur in Distillate Fuels

In the ongoing NORA/BNL research project related to maximizing fuel quality and performance (Ref 4), BNL is investigating the nature of fuel quality issues and will provide the oilheat industry with guidelines to begin to resolve these concerns. These issues are related to fuel instability, sludge formation, filter and nozzle fouling. Together they represent the largest number of unscheduled service calls in the oilheat industry. These problems are the result of numerous contributing factors, many of which are beyond the scope of this report. The instability of fuel oil and sludge formation are related issues that can not be separated. Contamination due to exposure to air, dust, humidity and other environmental factors combine with the chemical nature (and inherent instability) of the fuel as it was refined. Stability always degrades with time. It is related to the inherent instability of the product, how fast it is transported, the storage time and the use or nonuse of fuel stabilizers. Product roll-over and mixing with older product is also a factor. However, part of the problem is related to variations in the fuel chemistry including the feed stocks at the refinery (the source and type of crude). The type of the refinery processing to which the fuel is exposed is yet another factor as is the use of cracked stocks in blending the heating fuel product. The production of other products, refined for other markets such as gasoline, how the barrel of crude is cut up, is another factor, which can vary seasonally. These factors all can have an affect on the chemical stability of the heating fuel. One of the ways chemical degradation can occur is related to the reactive compounds based on sulfur and nitrogen found in the fuel. Although the exact mechanisms are still not known, reactive hydrocarbons, sulfur and nitrogen compounds contribute to fuel instability. Hydrotreating is currently the most

viable refining process for removing sulfur in diesel; nitrogen containing compounds are also removed by this process. Known or anticipated effects of hydrotreating on fuel properties include improvement in fuel storage.

In the NORA/BNL fuel performance research project, initial test results reported to date indicate that **low sulfur** (less than 0.05% sulfur by weight) fuels are **more stable** and generate less particulate matter than normal sulfur content fuels. The sulfur content of the fuel appears to be an indicator of the chemical stability of the fuel. In addition, the fuels treated with after-market stabilizing additives of the same sulfur classification were more stable and generated less particulate matter than untreated fuels of the same sulfur classification. In all cases reported, stability numbers for the low sulfur content fuel samples fell within the higher (more stable) end of the range.

The study is not yet complete and only a few marketers in the nation currently market low sulfur heating fuel. However, all evidence collected to date does support the conclusion. The use of low sulfur fuels will not eliminate all fuel stability problems and will not resolve many fuel related service calls. As stated earlier, many factors other than fuel chemistry contribute to fuel stability problems. The stability tests that exist are more comparative than predictive. The basic conclusion that lower sulfur levels do correlate to better fuel stability has been reported in other end use sectors as well as reported in several references. At this time all available data indicate that the use of low sulfur fuels will help improve the fuel quality.

5.0 Environmental Costs and Externalities for Low Sulfur Fuel Oil and Other Sources

Environmental costs, sometimes called externalities, were developed in order to evaluate the impact of electric power generation on the environment. Environmental cost factors have been historically estimated by evaluating the impact of various air pollutants on the environment by assigning a cost value (in dollars per pound) for each air pollutant that is emitted. These cost factors sometimes reflect measured values such as crop damage and other times are based on other values such as a cost of control equipment to reduce air pollutant omissions. These “environmental costs factors” are then added together and compared to evaluate the overall impact of all air emissions from different combustion sources. This is a complex subject matter has been evaluated for many years by groups including the Pace University Center for Environmental Legal Studies, the New York State Energy Office and the Massachusetts Department of Public Utilities.

A spreadsheet table in the NORA/DOE interim report compares the Environmental Costs of various fuels in \$ per Million BTU of fuel consumed. The spread sheet table (Ref 6) shows environmental costs for various combustion sources based on the above environmental cost factors, in dollars per pound, and actual emissions rates of all air pollutants by each fuel. The actual emission rates are based on publications by the U.S. EPA and test conducted by BNL. The lowest values are: Low sulfur No. 2 oil at \$1.36, natural gas at \$1.65, and No. 2 fuel oil (0.25% sulfur) at \$1.80 per Million BTU of fuel consumed. These are all much lower than most other combustion sources, and, therefore, produce the least environmental damage. Diesel engines and #6 fuel oil are higher in the range of \$5 to \$6 per Million BTU. Coal and gasoline powered engines are much higher at \$14.64 and \$18.45 per million BTU. The highest environmental cost

is for wood stoves at \$35.69 per million BTU, which is 20 to 25 times higher than oil or natural gas equipment. Clearly ASTM No. 2 oil and natural gas equipment produce comparable and very low environmental impact, and are much cleaner than all other combustion source that were evaluated. In fact, when the methane leakage from gas pipelines is included, low sulfur No. 2 oil has an environmental cost that is slightly lower than natural gas. These environmental costs for low sulfur fuel oil and other fuels are compared in the Figure 4.

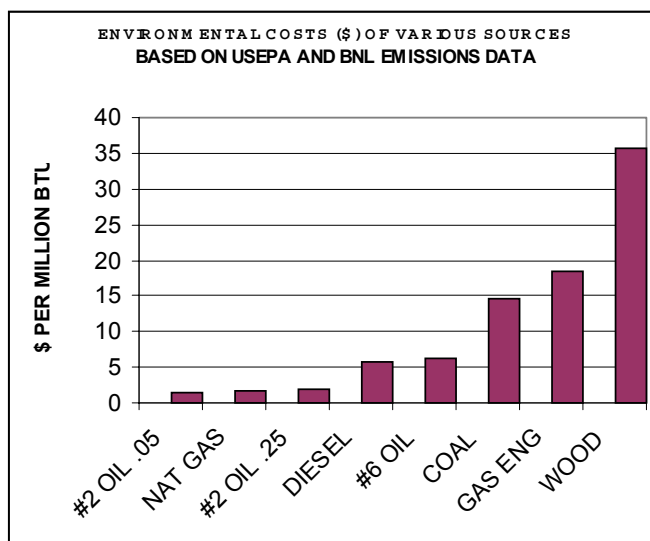


Figure 4

6.0 Field Tests by the New York State Energy Research & Development Authority

NYSERDA has been conducting a multi-year evaluation of the benefits of low sulfur heating oil in homes over the past two heating seasons with the assistance of the Energy Research Center, Inc and BNL, the Empire State Petroleum Association, and Buhrmaster Energy Group in Scotia, New York. NORA is co-funding Phase II of this work which is ongoing at this time. The objective of this project is to demonstrate the advantages of low sulfur fuel oil in actual homes, measure the performance improvement, evaluate potential reductions in cleaning costs, and identify problems with its widespread use. Initial estimates indicate potential reductions in service (vacuum cleaning) costs as high as \$56 million a year in New York State.

This study involves one entire division of the customer base, approximately 1,000 homes which receive low sulfur (0.05%) heating oil in comparison to the other delivery divisions of the Buhrmaster Energy Group that receive normal heating oil. The baseline or normal fuel has typically been 0.15 to 0.20 % by weight in sulfur content. Work included tracking fuel use statistics and service requirements for the different groups, regular and low sulfur content fuel use. It is worth mentioning that the Buhrmaster Energy Group has experienced no negative issues related to delivering the low sulfur fuel, no unusual non-scheduled service issues and no consumer complaints over the entire three year study. The one comment by members of the

service department is that the technicians prefer assignments working with the equipment that have received the low sulfur product because it has a much more pleasant odor, more neutral in odor, in comparison to the homes using regular fuel.

6.1 Deposition Data and Analysis

A sub-set of twenty homes out of the 1,000 homes included in the broader study was selected for a more detailed investigation into the issues associated with fouling deposits. This also included a similar sub-set of the homes receiving regular sulfur content fuel as a control group. These boilers in the test program were cleaned by specially trained oilheat service technicians using a method developed at BNL for collecting all the boiler deposits and placing them in a sample bottle for analysis. Figure 5 summarizes the data analyzed to date.

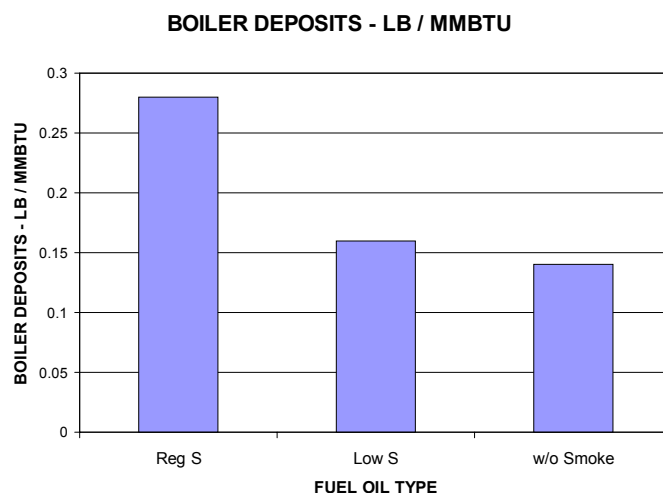


Figure 5

The normal sulfur fuel oil produced **0.28 pounds of deposits** per million BTU of fuel consumed. This is significantly higher than the deposits from the low Sulfur boilers. When the “heating only boilers” and with “high smoke number boilers” are removed, the average deposits in the low sulfur group equals **0.14 pounds** per million BTU of fuel. This is a two to one (**2:1**) reduction in deposits for the low sulfur oil. This is consistent with the laboratory results obtained from detailed studies at both BNL and the CANMET Energy Technology Centre in Canada.

6.2 Visual Inspection Data and Analysis

As part of the evaluation program for the NYSERDA field study, BNL engineers developed a **Visual Fouling Scale** that was used by service technicians to evaluate the level of deposition on the heat exchangers prior to cleaning. This fouling scale was applied to the detailed study homes, and also in about 100 other homes to see how the visually observed scaling compares for the normal sulfur and low sulfur homes. Excellent correlation was observed between this fouling scale and the mass of deposits collected for the normal and low sulfur homes. Figure 6 shows that the Visual Fouling Scale averages for normal and low sulfur homes. It is very similar to the measured differences in deposition mass shown in Figure 5, with about a two to one (2:1) difference.

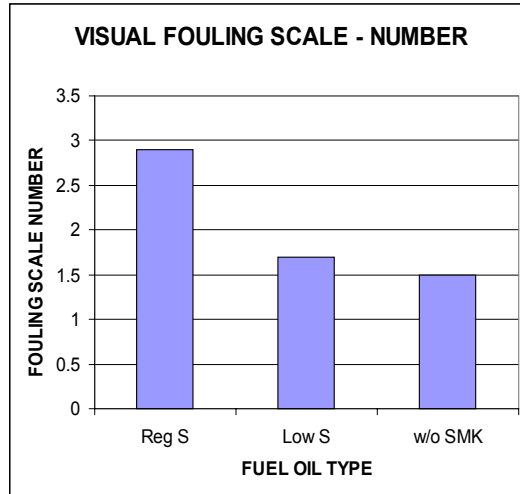


Figure 6

A similar difference in fouling factors was obtained for approximately 100 normal and low sulfur homes that did not have their deposition rates measured (Figure 6). The average Visual Fouling Scales for the Normal sulfur homes in this group was 2.6, and for the low sulfur homes was 1.7. The visual fouling scale appears to accurately predict the measured deposition rates, and gives similar difference when comparing the normal and low sulfur fuels.

In terms of the effect that the use of low sulfur had on the service requirements for the division receiving low sulfur fuel, BNL and ERC sought input from the Buhrmaster Energy Group. The selected division required three full time service technicians prior to the beginning of the low sulfur marketing study. After two years of experience with delivering the low sulfur content product the service requirements have decreased to the point where this division is serviced by the equivalent of one and a half technicians per year. This is a fifty percent reduction in terms of the costs to satisfy the service required by this division. In addition this division now contains almost two hundred additional homes as compared to the beginning of the study due to additions brought on by an acquisition of another fuel delivery company by the Buhrmaster Energy Group during the three year period.

This field study is important because it is the first documented long-term evaluation of the performance of low sulfur fuels in actual homes. It validates many years of laboratory testing and demonstrates the important advantages of low sulfur fuel oil in homes served by oil marketers.

7.0 Preliminary Cost Saving Potential

In the DOE/NORA report a preliminary evaluation of service cost savings was completed using the BNL/CETC data on reduced boiler deposition rates. This was combined with information from a survey conducted by the National Association of Oilheat Service Managers (NAOSHM) and RW Beckett Corporation two years ago (Ref 7), which shows average values for: existing service intervals, labor costs for service, and the time required for vacuum cleanings. This evaluation is summarized in Figure 7 which shows potential costs savings nationwide. More details on these preliminary cost saving estimates are included in the interim report. The data is

preliminary for now as a more detailed investigation into the range of factors involved and the source data for service rates and job time factors is required to finalize the calculations.

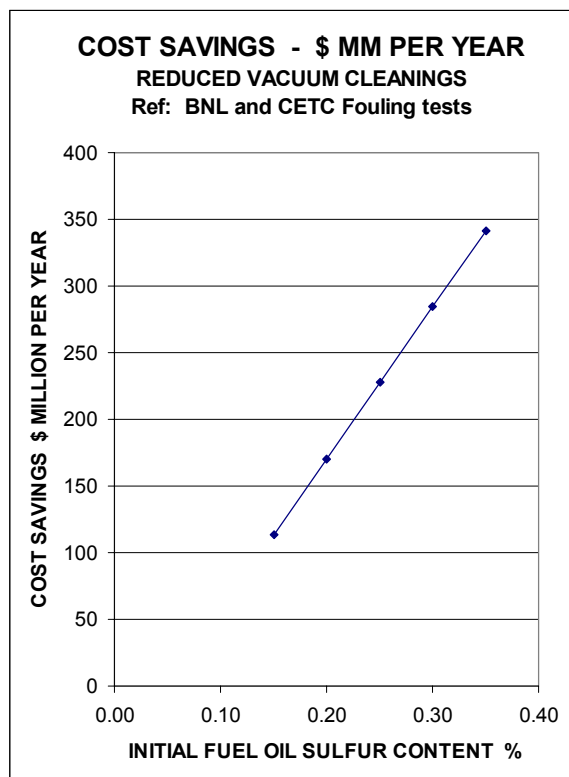


Figure 7

8.0 References

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Ref 2. United States Environmental Agency, AP-42, Fifth Edition, Volume 1, Chapter 1: External Combustion Sources, Table 1.3-1 Criteria Pollutant Emission Factors for Fuel-oil Combustion, Table 1.3-2 Condensable Particulate Matter Emission Factors for Fuel-Oil Combustion

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associated presentation viewgraphs provided at the NORA Technology Symposium at the Oilheat Visions Conference, August 19-20, 2002

Ref 5. Oilheat Advantages Project – Engineering Analysis and Documentation Report by J.E. Batey and R. Hedden, Copyright 1995 by the Oilheat Manufacturers Association

Ref 6. Advantages of Low Sulfur Home Heating Oil, Interim Report of Compiled Research, Studies and Data Resources, National Oilheat Research Alliance and the United States Department of Energy, Prepared by: John E. Batey, Energy Research Center Inc. and Roger McDonald, Brookhaven National Laboratory, December 2002 (Available from the National Oilheat Research Alliance.)

Ref 7. Letter to ASTM Subcommittee EW Chairman, from Victor Turk of the RW Beckett Corporation, dated December 2, 1999, regarding proposed revisions to fuel oil specifications, and supporting engineering analyses of the impact on heating equipment cleaning intervals of lower sulfur oil.

9.0 Acknowledgements

The authors would like to acknowledge the sponsors of the combined effort reported in this paper namely, the United States Department of Energy represented by the DOE program manager, Mr. Ronald Fiskum, the National Oilheat Research Alliance represented by the President of NORA, Mr. John Huber, and the New York State Research and Development Authority represented by the NYSERDA program manager, Mr. Raymond Albrecht. The authors also wish to acknowledge the research contributions quoted in this paper as made by Dr. S. Win Lee of the CANMET Energy Technology Centre in Canada, Mr. Victor Turk of the R.W. Beckett Corporation (including information on service cost estimates obtained from the National Association of Oil Heat Service Managers) and the entire staff of the Brookhaven National Laboratory Oilheat Research program who have conducted over ten years of research on the subject of low sulfur fuel related mechanisms and their impacts on residential heating equipment. Additional information cited was obtained for the United States Environmental Protection Agency internet web site.

Paper No. 07-03
The Green Fuel Option for the Oilheat Industry – Biofuel Research

C.R. Krishna, Ph.D. and Roger J. McDonald
Brookhaven National Laboratory
Building 526
12 North Six Street
Upton, NY 11973
Phone: 631-344-4025
Phone: 631-344-4197
Fax: 631-344-2359
E-mail: krishna@bnl.gov
E-mail: mcdonald@bnl.gov
Internet: www.bnl.gov

Funded jointly by:
United States Department of Energy
&
NYS Energy Research & Development Authority

The Green Fuel Option for the Oilheat Industry - Biofuel Research

C.R. Krishna, Ph.D. and Roger McDonald

Brookhaven National Laboratory

Abstract

Brookhaven National Laboratory has completed several projects related to extending fuel resources by using fuel blends of bio-sourced liquid fuels and heating oil. A summary of findings and conclusions from BNL's research along with experience gained by others will be the core of this presentation which will introduce this green fuels session which can help promote the clear burn science of oilheat. Laboratory studies and field results associated with burning biodiesel fuel oil blends will be discussed both for small residential appliance applications as well as commercial boiler use. Biodiesel has been tailored as a replacement for diesel and it was suggested that for continuous combustion applications, such as boilers, relaxing the ASTM specifications with regard to requirements such as acid content, cetane number, and glycerine content might make this easier for heating applications. Such a product could be cheaper (potentially) and hence could find more acceptance for use as a boiler fuel. Research involving a potentially lower cost alternative using soy methyl ester as the blend stock was recently completed and these results will also be discussed during this presentation.

1.0 Introduction

Renewable fuel and energy are becoming an increasingly visible part of the fuel and energy market in the U.S. There are a number of reasons for this, such as the notion of fuel independence, the intent to diminish the reputed global warming effects, and public policy among others. The use of renewable fuels is not particularly novel, as wood was a significant fuel used in homes, industry and transportation for a long time before so-called fossil fuels, coal, oil and gas, began to supplant it. Liquid fuels derived from renewable sources were much less in use, excepting for vegetable oils used for lighting primarily. It is a matter of historical curiosity that Rudolf Diesel, the inventor of the well known engine that bears his name, used peanut oil as one of the fuels for his engine. Obviously, edible vegetable oils were much more valuable in food! The diesel engine, along with other internal combustion engines, notably the auto (Otto) engine, were developed to use petroleum derived fuels which began to be available around the same time. In recent times, there have been efforts to generate liquid fuels from biomass through gasification and pyrolysis that could be used in boilers and also to 'refine' vegetable oils to produce fuels that could be used in diesel engines. The latter effort has resulted in the development of what is appropriately called biodiesel from various vegetable oils, primarily soy oil in the U.S. and mainly from rapeseed oil in Europe. Biodiesel can also be produced from used vegetable oil such as the 'waste' from fryers and also animal fats. The potential use of the biodiesel as blends with petroleum diesel in diesel engines has resulted in the development of an ASTM standard D 6751-02 parallel to that for petroleum diesel. Europe had adopted earlier a standard suited to its provenance.

While the biodiesel has properties similar to the petroleum diesel for the most part, there are some significant differences in the composition of the fuels. One such difference is that biodiesel has about 10% by weight of oxygen in it, while diesel has none. Also, conventional diesel and home heating oil have significant amount of sulfur, the ASTM standard D396-02 allowing a maximum of 0.5%, although local values generally are lower. Of course, the current low sulfur

diesel standard for highway use is already down to 0.05%. On the other hand, biodiesel tends to have almost no sulfur and the ASTM 6751-02 requires a maximum of 0.05% (equivalent to the low sulfur diesel).

Brookhaven National Laboratory (BNL) has investigated the potential for use of blends of biodiesel in home heating oil over the last several years, in home heating and in small commercial boilers. Field tests of biodiesel blends have also been carried out by Abbott and Mills, a fuel oil dealer in Newburgh, New York in about a hundred homes over the last two heating seasons. More recently, it was suggested by BNL that for boiler applications, all the requirements of the ASTM standard may not be needed and hence a fuel from the same vegetable and animal fat sources that is not 'refined' to this rigorous requirement could be acceptable. The potential exists that such an 'off-spec' fuel, called biofuel here to distinguish it from biodiesel, could be potentially cheaper and thus find wider acceptance. This could be important in enhancing the use of biofuels, as biodiesel generally costs more per gallon than petroleum diesel under current market conditions. Combustion tests of blends of such a biofuel product in both home heating oil and residual oil have been recently carried out. We will describe below the results obtained so far with biodiesel blends and biofuel blends in the laboratory and also the practical experience of Abbott and Mills in using biodiesel blends in the field.

2.0 Laboratory tests on Biodiesel Blends

The laboratory tests were planned partly to determine under what conditions blends of biodiesel in home heating oil could replace home heating oil with none or minimal changes to the system. Clearly, the first requirement for this to be possible is that the physical and combustion properties of the blends and the home heating oil are closely similar. Hence, these were measured first. The next requirement is to demonstrate that the blend performs similarly to the heating oil in the burner and boiler combination, so that one can take it to a field test with a level of confidence.

The fuel properties were measured by petroleum fuel test laboratories. The combustion tests were carried out in the oilheat laboratory at BNL. The combustion test on the blends were conducted without altering the burner settings that had been obtained using normal home heating oil. This was felt to be necessary as it would not be practical to change the settings in every home when the blend is substituted for the regular heating fuel. If a marketer were to establish along term relationship with a biofuel supplier, the oilheat systems could of course be adjusted to take advantage of the maximum benefits from using biofuel blends as will be discussed in this paper. When dealing with the realities of the market place and allowing for the possibility that biofuel may not always be available, having the option to switch back and forth seems prudent initially. This was the position that BNL took in designing its original research for investigating biofuel blends .

2.1 Properties of Biodiesel Blends Compared

Figure 1 below compares the viscosity of the blends. Obviously, viscosity has an effect on the pump pressure and the flow rate through the nozzle. It is seen that the viscosity varies from about 2.7 CentiStokes for this sample of #2 fuel oil to a little less than 4.5 for the neat biodiesel. The allowable range for # 2 fuel oil according to ASTM D396-02 is 1.9 to 3.4. This would indicate

that the viscosity is in an acceptable range for a blend up to about 50% biodiesel for the present blends.

Figure 2 gives the flash point for the blends. The ASTM requires only a minimum of 38⁰ C for #2 fuel oil. Biodiesel has a value of over 120⁰ C and hence all the blends have a higher flash point. While this is certainly a positive from the safety point of view, the high flash point of the biodiesel might make it difficult to ignite under extreme cold conditions with conventional equipment.

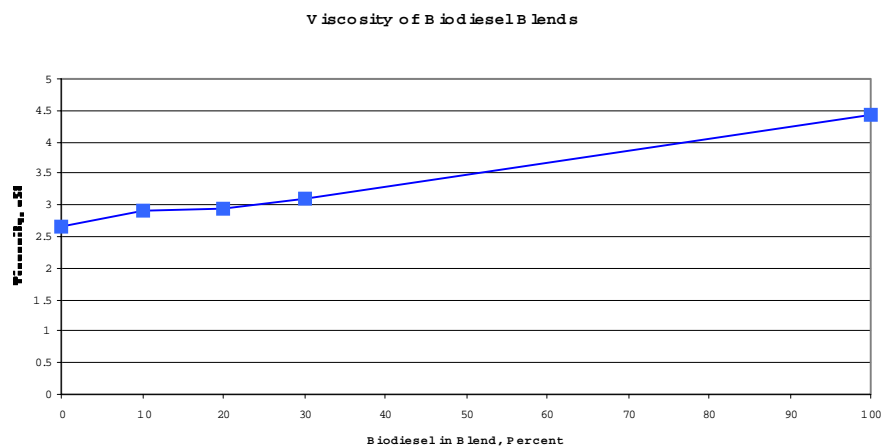


Figure 1. Viscosity of Biodiesel Blends

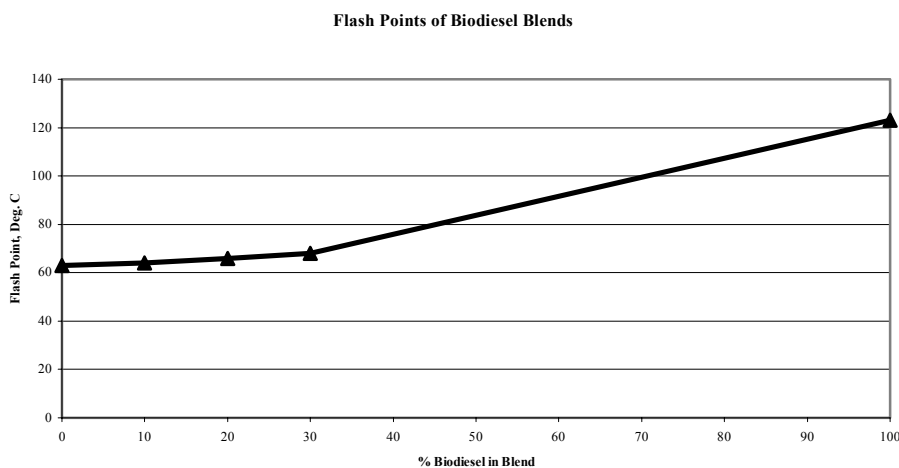


Figure 2. Flash Points for Biodiesel Blends

Figure 3 shows how the pour point temperature increases, that is the cold flow properties become worse, with increase in biodiesel concentration. The ASTM requires a maximum pour point of – 6⁰ C for # 2 fuel and it would seem that this is met at biodiesel fractions up to 70% for these blends. This property is primarily important for storage conditions outside occupied space in the winter months. As these conditions vary between locations, fuel oil dealers normally use, when

required by the local temperatures, additives to depress pour points. Though additives were not tested in this study, it has to be observed that heating fuel additives may not work or work as well with biodiesel blends. Additional information needs to be generated in the area of cold storage and flow for biodiesel blends.

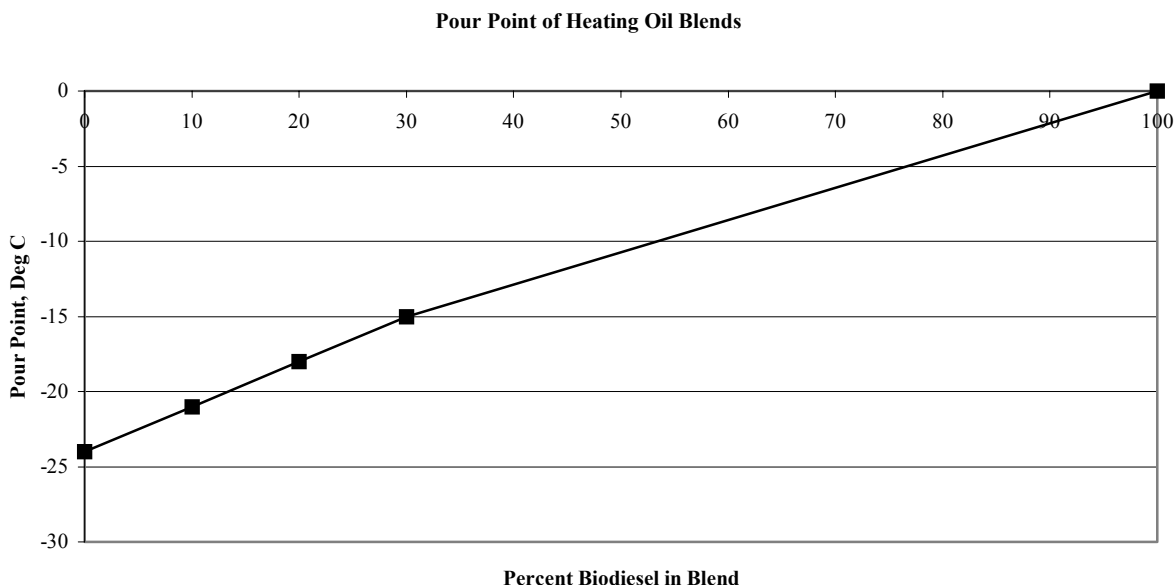


Figure 3. Pour Point of Biodiesel Blends

2.2 Combustion Tests

The combustion tests were carried out as indicated above with burner settings identical to those with #2 fuel oil and as recommended by the burner/boiler manufacturers. The smoke numbers were similar for the blends and the neat fuels. Figure 4 below compares the carbon monoxide measured in the stack for the heating oil and for the 20% blend, designated B20, for example. The carbon monoxide is slightly lower with blend for most of the range of excess air as given here by the oxygen in the stack. This could be the result of the biodiesel having oxygenated compounds.

Figure 5 below compares the NOx emissions from combustion tests. It is seen that over most of the operating range, the addition of biodiesel reduces the NOx. This was unexpected as most previous tests in engines had shown not much difference. As will be seen below, it was even more pronounced in the commercial boiler tests. While NOx emission is not regulated in residential boilers, this adds to the benefit of biodiesel as a environment friendly fuel.

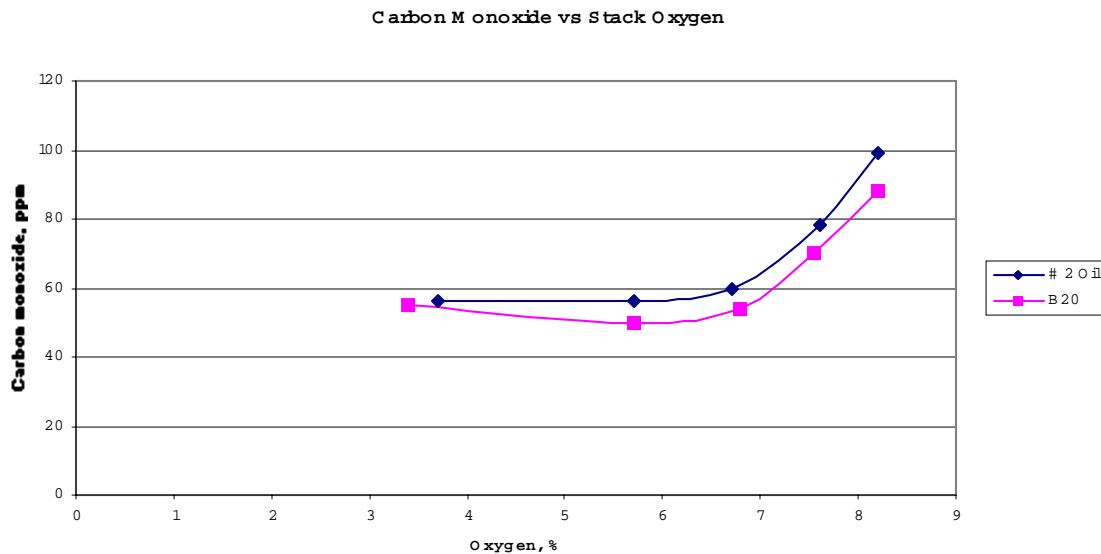


Figure 4. Carbon monoxide emission in residential boiler tests

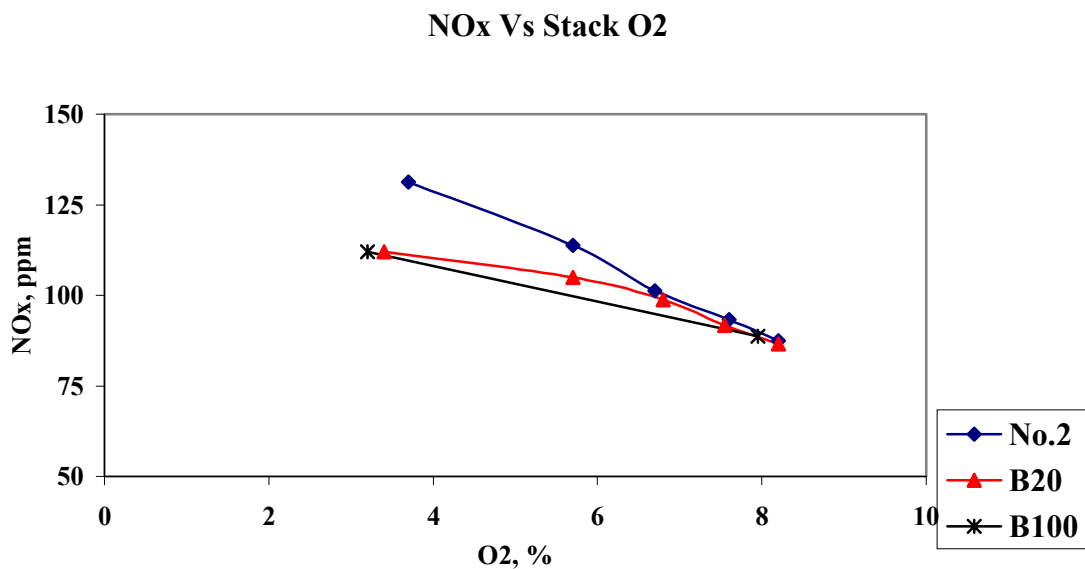


Figure 5. NOx Emissions in Residential boiler tests

Figure 6 compares the NOx emissions from the commercial boiler tests. It is seen that the NOx reductions from the biodiesel blends are even more significant than in the residential boiler tests. The NOx emission with neat biodiesel is over 30% less than with #2 fuel at similar stack oxygen levels.

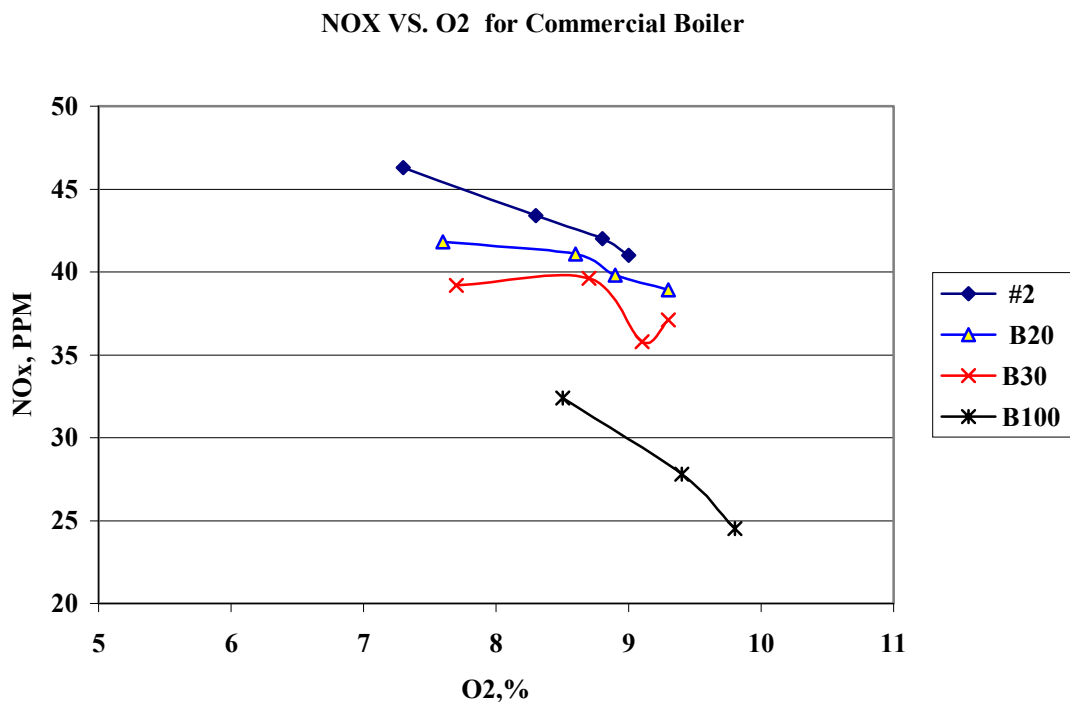


Figure 6. NO_x emission in commercial boiler tests

2.3 Biofuel Tests

As indicated in the introduction, a potentially cheaper source of biofuel to make blends for boiler use would be desirable. One such product, which is called Soy Methyl Ester (SME) in the following, is available as a possible fuel source. Biodiesel is essentially a soy methyl ester, if produced from soy oil, but is refined to reduce the residual fatty acid content and glycerine. Blends of the SME in # 2 fuel oil were made similarly to those with made with biodiesel for the previous tests and similar testing was carried out. In the case of the biofuel, blends were also made with residual fuel and a small number of tests were conducted in burning these in the commercial boiler.

2.4 Properties of Biofuel Blends in # 2 fuel oil

We will compare in the following three figures the properties of biofuel blends made in # 2 fuel oil. Figure 7 shows that the viscosity of the SME blends tested were slightly higher than those of the biodiesel blends. It can be seen that the viscosity of the base #2 oil was also higher (0% blend points) and hence the trend might just reflect that. The viscosity as reported here would put the blends beyond the range specified in ASTM D-396. Figure 8 compares similarly the flash points and again the values for the biofuel blends are higher, though only by a few degrees Fahrenheit. The conclusion made with biodiesel, that this could make ignition of high concentration blends difficult, especially under cold temperature conditions holds good here as well. Figure 9 compares the cold flow properties of the biofuel and biodiesel blends as given by the measured pour points. It can be seen that the SME or Biofuel blends have slightly higher pour points and the increase might very well be due to that in the base # 2 fuel oil. (Compare the points at 0%). In this case, the ASTM requirement of -6°C maximum is met by blends of up to about 50%.

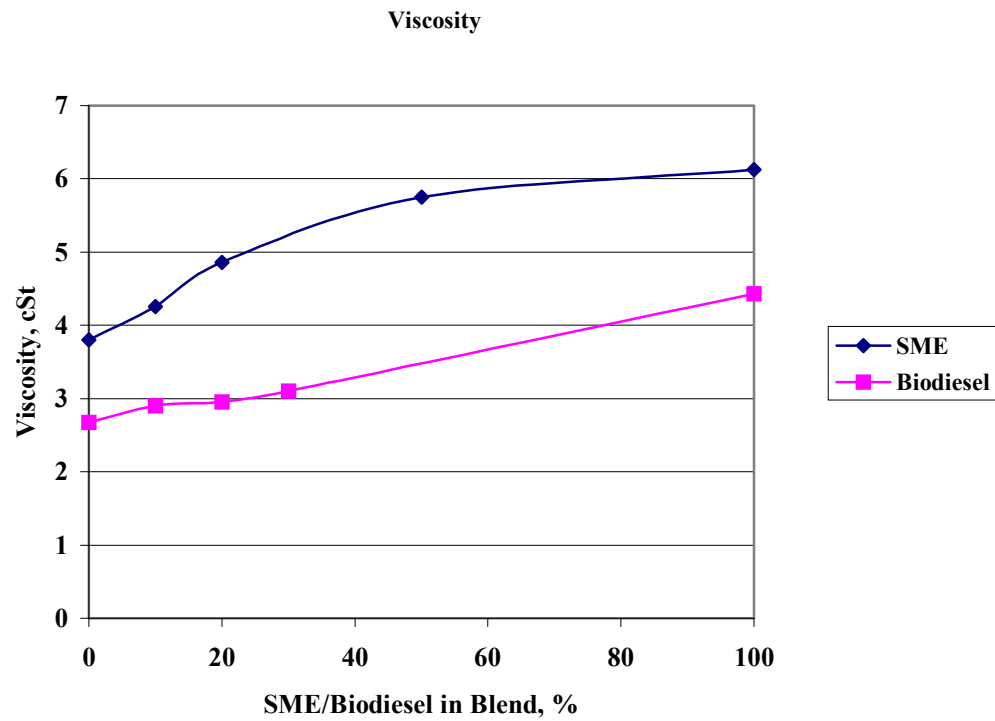


Figure 7. Viscosities of Biofuel and Biodiesel blends in #2 fuel

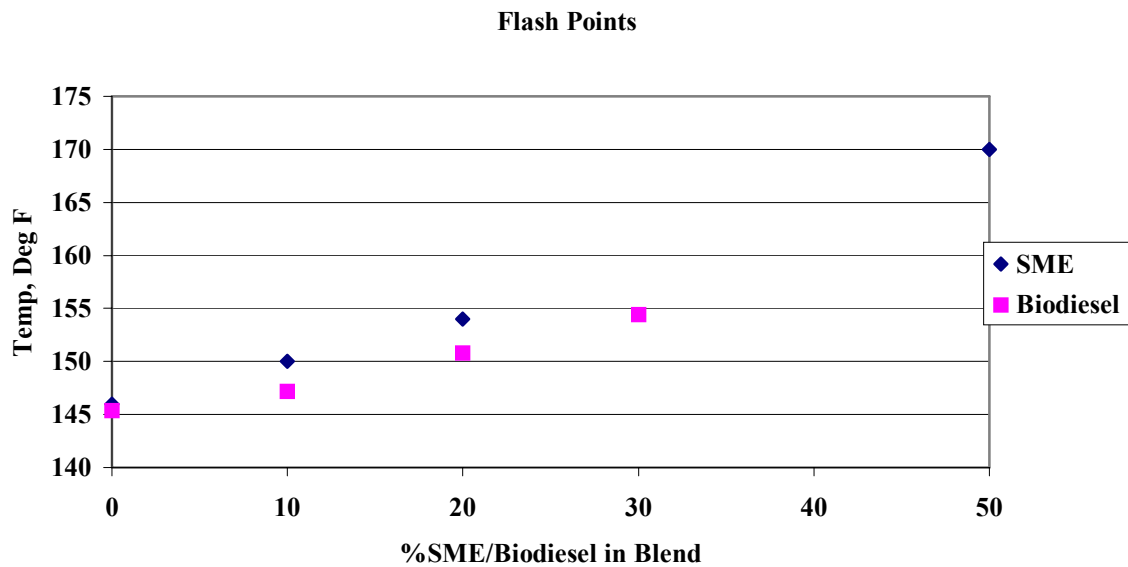


Figure 8. Flash Points of Biofuel and Biodiesel blends in # 2 fuel

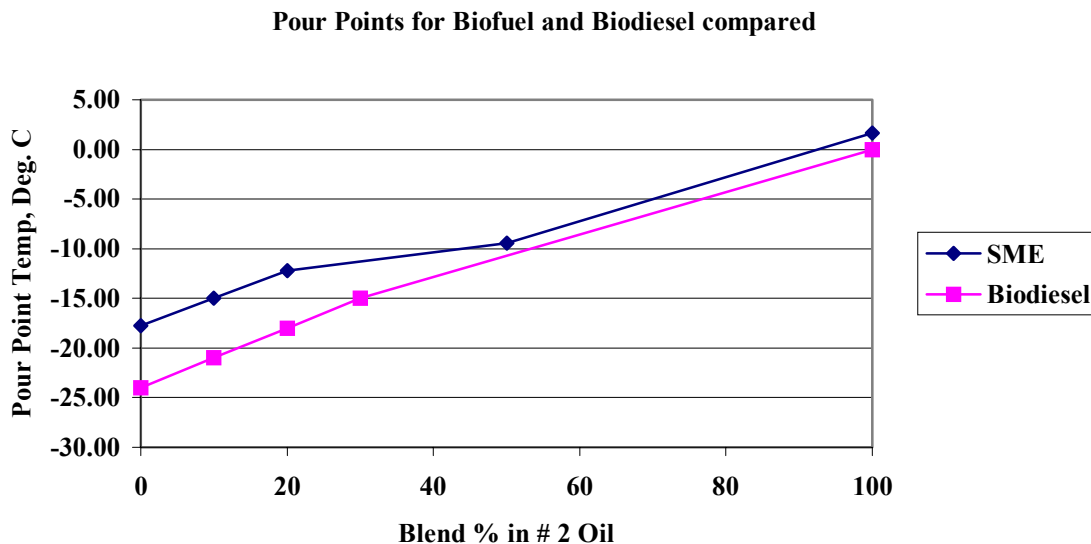


Figure 9. Pour Points for Biofuel and Biodiesel Blends

2.5 Combustion Tests of Biofuel blends in home heating oil

The combustion tests in the residential and commercial boilers were carried out in conditions as close as possible to those used in the biodiesel tests. The next few figures give the results, which, not surprisingly, are similar to those with the biodiesel blends. Figure 10 gives the NO_x emission from the residential boiler tests as a function of excess (represented by stack oxygen) and broadly speaking, the NO_x levels go down as the fraction of biodiesel in the blend goes up. The trend seems to reverse somewhat when we go to 100% SME. The reason for this is not clear and the result has to be confirmed.

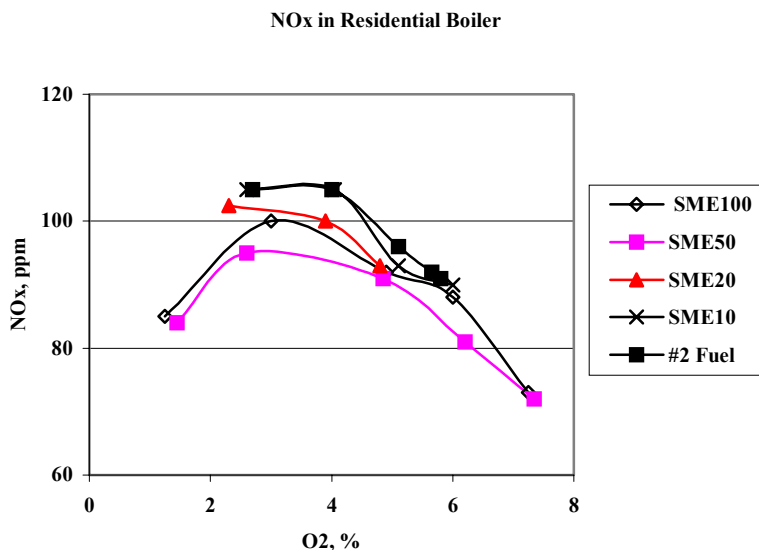


Figure 10. NO_x emission in residential Boiler firing Biofuel blends

Figure 11 is similar NOx emission data in the commercial boiler firing the Biofuel blends. Here, there is a reduction of NOx, at similar stack oxygen levels, as the fraction of biodiesel is increased to 100%.

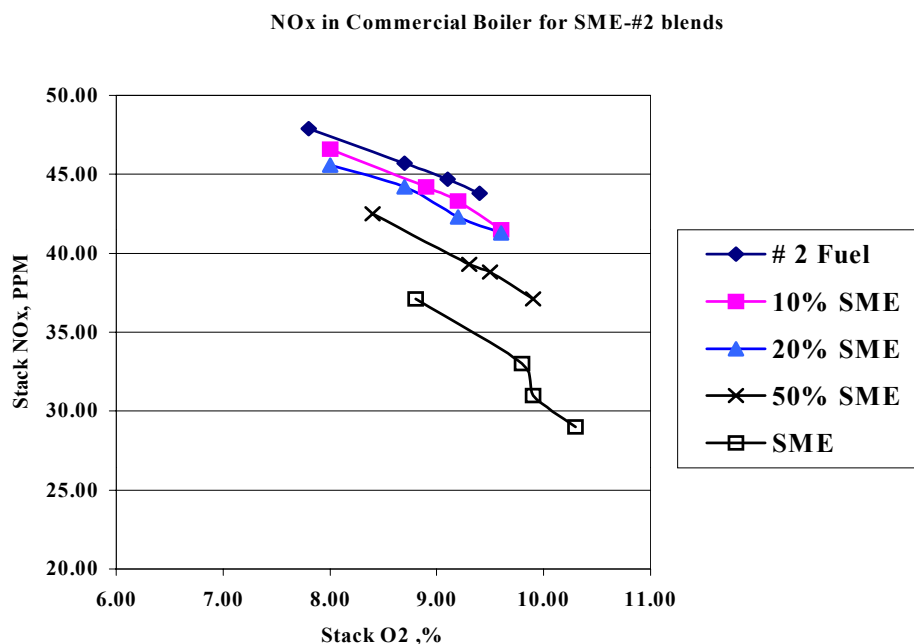


Figure 11. NOx emission in commercial boiler firing Biofuel blends

2.6 Field Tests of Biodiesel

As reported previously, Abbott and Mills of Newburgh, New York have been supplying a B20 blend to about 100 of their customers since the 2001-2002 heating season. They have continued the project through the heating season just ended. They have supplied over 60,000 gallons and report that ‘no news is good news’, meaning that they have not received any complaints specific to the biodiesel blend fuel from the customers using it. While the heating season of 2001 was relatively mild with only a few days of single digit temperatures, the 2002 winter was much more severe. This suggests that the procedure they have used to store, mix and deliver has been satisfactory for at least a 20% blend from the point of cold flow.

3.0 Bio-fuel Marketing Considerations for the Residential and Light Commercial Oilheat Industry

3.1 Blending Biofuel and Blending

Several marketers have already explored the marketing of biofuel blends on a small scale. [In this section the term biofuels will be used to describe either biodiesel or alternative liquid bio-derived fuels used in fuel oil product blends.] The experience gained to date can be very useful as more fuel oil marketers consider the economic opportunities of biofuel marketing. The physical characteristics of biofuels in cold climates require special consideration be given to the storage of pure (neat biofuel) given its cold-flow properties. The fuel marketer in Newburgh, NY, for example, blends biodiesel with heating fuel in the delivery tank truck used to service the

customers using the blend. The marketer obtains pure 100% biodiesel and stores it in a spare tank trailer kept in a warehouse type structure that is heated above 69F. In this way the biofuel is always ready for the blending process. The pure biofuel is pumped into the delivery tank truck to a level of twenty percent of the desired quantity of blended product and then normal fuel oil is added at a high rate of fill to the truck. This marketer has found that the high rate of fill for the normal fuel provides for adequate blending of the product. It would be important to provide some alternate means of blending the product if the fill rate were at much slower. Based on all experience to date, once blended the blend is stable and the blended product does not exhibit any tendency to separate.

3.2 Optimization of Air/Fuel Ratios with Biofuel Blends

As stated, BNL has supported a cautious approach when dealing with burner settings to avoid issues related to necessitating returning to a home every time the fuel is switched from either biofuel blends to normal heating oil or the reverse. In fact if a marketer were to be assured that he had a steady supply of blended biofuel product for his customer base that marketer could enhance the benefits derived by his customers by adjusting the air/fuel ratio in each customer's home. A study conducted by Energy Research Center Inc. for the Massachusetts Oilheat Council and funded by the National Oilheat Research Alliance (NORA) has observed that when optimized a 20% biodiesel/highway diesel blend can operate with a measurable decrease in excess air when compared to normal heating fuel alone. The shift in smoke number from the bio-blend to heating fuel translated to a shift in smoke number as measured of about 3 smoke numbers on the ASTM scale. The biodiesel is an oxygenated fuel with approximately 10% oxygen by weight. This also resulted in somewhat lower carbon monoxide measurements found in the ERC/MOC/NORA study.

4.0 Acknowledgement

The work on biodiesel in our laboratory was initially funded by DOE through NREL (K.S. Tyson, program manager) and has been subsequently supported by NYSERDA. We thank Raymond Albrecht, the program manager at NYSERDA for strong encouragement and support. NYSERDA funded the biofuel work as well through NOCO and we thank Gary Roesch, formerly of NOCO for support. We thank Skip Hauth, recently of NOCO for continued support. The experimental work was carried out through the efforts of George Wei and Yusuf Celebi. The work has benefited generally from the insights of Dr. Thomas Butcher.

Paper No. 08-03
Laboratory Investigations on the Cold Temperature Combustion and Emission
Performance of Biofuel Blends

S. Win Lee, I. He, T. Herage, and B. Young
CANMET Energy Technology Center-Ottawa
Natural Resources Canada
Ottawa, Canada. K1A 1M1
Phone: 613 996-3873
Fax: 613 992-9335
E-mail: swlee@nrcan.gc.ca
Internet: www.nrcan.gc.ca/es/etb/cetc

Short-term Laboratory Investigations on the Cold Temperature
Combustion and Emission Performance of a Biofuel Blend

S. Win Lee, T. Herage and B. Young
CANMET Energy Technology Centre
Natural Resources Canada
Ottawa, Canada. K1A 1M1
swlee@nrcan.gc.ca

ABSTRACT

The use of biofuel products in space and process heating, when properly blended with petroleum distillate oils, would promote energy efficiency and reduce green house gases and other harmful pollutant emissions. Biodiesels and biofuels that are processed from biological materials such as vegetable oils, recycled cooking oils and animal fats are being used by blending them with petroleum distillates to help offset the increasing energy demand. They are recognized as a renewable fuel source with promising environmental and economic benefits. Recently, biodiesel research has progressed favorably due to its great potential as an alternative transportation fuel. Biofuels that are not restricted by diesel fuel specification requirements can be processed at a lower cost than biodiesel and have promising potential in heating and industrial process applications. If biofuels can be used in such applications with no or little equipment modifications, significant benefits can be realized in several areas including energy costs, regional agricultural economy, emission reduction and extended equipment life.

Recent research and field demonstrations in the United States show positive outcomes from the use of biodiesel and distillate oil blends in residential heating. Canada has a keen interest in promoting the use of biofuels in residential heating to help offset high energy costs associated with colder winter climates. CANMET, the federal laboratory for Canadian energy research is currently exploring the cold temperature combustion and emission characteristics of biofuel/distillate oil blends. The combustion experiments are being conducted using a blend containing 20% soybean methyl ester in No. 2 fuel by volume in a temperature controlled test room. The fuel blend burned satisfactorily in a wet-based residential hot water boiler with no modifications to the combustion appliance and the fuel delivery system. Initial laboratory trials indicate that the blend showed acceptable cold temperature performance at temperatures above 15°C. The fuel temperature has a significant impact on the generation of incomplete combustion products such as soot and CO. Based on short-term experimental data, a minimum fuel temperature of 10°C is recommended to avoid generation of soot that can build up over time on the combustion appliance components.

Sulphur dioxide emissions of the 20% biofuel blend were found to be 19.7 ± 2.5 % lower than that of No.2 fuel while nitrogen oxide emissions were similar for both fuels. Particulate emissions from the biofuel, when determined using a source dilution particulate measurement system, are on average 15.7 ± 7.5 % lower than that of No. 2 fuel. Since particulate are mostly made up of PM_{2.5} emissions this observation is considered significant in reducing these fine particle emissions. Similar reductions in particulate bound sulphate, by 14.1 ± 6.1 %, were also noted. These initial findings indicate the potential benefits in emission reduction as well as energy efficiency and resource management flexibility. Reduction of PM_{2.5} that are associated with adverse health effects is an important consideration for the oil heating industry and the advantages of using different biofuel blends should be investigated further in view of these benefits.

INTRODUCTION

New and increasingly stringent environmental regulations are being ratified globally due to heightened awareness of harmful effects associated with ambient air pollution. The use of renewable fuels as an alternative energy source is an attractive option since these fuels can provide benefits such as increased energy efficiency, improved policy options for resource management and sustainable development and in reducing green house gases and harmful emissions. Reduced dependency on external oil imports and fluctuating energy prices can also be realized if ever-increasing global energy demands can be partially subsidized by renewable sources. Recently, applications of alternative liquid fuels derived from biological materials such as vegetable oils and recycled animal fats have gained recognition and support by regulators and industrial sectors, especially for compression ignition engines. At present, a wider scope of research exists for several investigations relating to biodiesel performance in diesel engines for commercial and military applications (1, 2). Biodiesel is a loosely termed name for the alternative diesel fuel derived from the transesterification of oils contained in biological materials. The product is basically methyl or ethyl esters containing several alkyl groups with C15 to C17 hydrocarbon chains, collectively known as fatty acid alkyl esters. Their properties are similar to diesel fuel in performance in compression ignition engines. Soybean methyl ester fuels are the most common biodiesels in North America. Biofuel is another loosely defined name for mono alkyl ester fuels that may or may not meet the biodiesel specifications developed for diesel engine operation. Biofuels are normally less costly to produce than biodiesels and they are also obtained as byproducts from manufacturing industrial products such as additives, vitamins and special chemicals. Significant opportunities exist if biofuels can replace a certain percentage of distillate fuel demand in North America since soy based methyl esters are readily available and economically viable to produce both in Canada and the United States.

A research program was recently initiated in the United States to investigate the performance of biodiesel in space heating equipment (3). The results demonstrated that the fuel containing 20% biodiesel and 80% No. 2 oil, termed as B-20 blend, exhibited acceptable normal combustion performance on oil-fired units. No modifications to the combustion and fuel delivery systems were necessary. While combustion emissions are also similar to those of No.2 fuel oil, noticeable reductions in stack SO₂ and NO_x emissions from biodiesel blend were reported. This indicated significant advantages of biodiesels, providing incentives for the oil heating industry to use them in view of positive gains in production cost, energy conservation measures and environmental management.

Canada has a keen interest in the application of biodiesels and biofuels as well. However, Canada's colder climates dictate more stringent low temperature operability of the fuels. The cloud point of the blend is higher than that of No. 2 fuel and could present operational problems due to filter plugging when paraffinic materials in biofuel solidify at low temperatures. A research program was recently initiated to study the suitability of biofuel blends as commercial fuels for residential space and water heating in Canada. Potential reductions in fine particulate matter (PM) that can be realized from these renewable fuels are also being investigated. This is important in view of the new Ambient Air Quality Standards in Canada and the US that limit the ambient concentrations of fine PM, commonly known as PM_{2.5} and PM₁₀ (4, 5). These are the particles with an aerodynamic diameter less than 2.5 µm and 10 µm, respectively. The new North American regulations are based on their reported associations with adverse health effects including lung cancer and cardiopulmonary ailment (7-9). Whereas energy and environmental

benefits of renewable fuels are well recognized, information on their advantages relating to health impacts is relatively scarce. This paper reports initial findings from this new research initiative with respect to the potential gains from biofuels that could be realized in the areas of energy efficiency and environmental and health impacts.

MATERIALS AND METHODS

Experimental Fuels

This investigation employed a commercial No. 2 type heating oil and a blend containing 20% soybean methyl ester in No. 2 fuel by volume. The soy ester was produced in Canada using a proprietary process and was provided by a local fuel supplier. The biofuel blend is normally referred to as B-20. This blend ratio was selected based on the research conducted at Brookhaven National Laboratory. The blend is properly mixed and mechanically agitated prior to each combustion experiment to ensure fuel homogeneity. The drums containing test fuels are stored and conditioned overnight in the temperature controlled test room to achieve desired test temperatures. Table 1 gives properties of the test fuels. The No. 2 oil is used as the reference or control fuel for the performance evaluation of the biofuel blend.

Table 1: Properties of No. 2 oil and B-20 biofuel blend

Properties	No.2 Fuel	B-20 Blend
Ultimate Analysis (wt %)		
Carbon	87.00	85.10
Hydrogen	13.10	12.90
Nitrogen (ug/g)	86.00	67.00
Sulphur (wt %)	0.19	0.15
Ash (wt %)	<0.001	<0.001
Water Content- Karl Fisher (wt %)	<0.01	<0.01
Total Acid Number (mg KOH/g)	0.09	0.32
Density @ 25°C (Kg/m ³)	839.9	847.9
Density @ 15°C (Kg/m ³)	847.2	855.2
Specific gravity (60/60F)	0.848	0.856
Gross Calorific Value (cal/g)	10831	10527
Kinematic viscosity @25°C (cSt)	2.991	3.416
kinematic viscosity @40°C (cSt)	2.234	2.549
Cloud Point °C	-16.4	-3.6
Pour Point °C	-38	-24

Fuel Oil Combustion Test Facility

A cast iron, wet based residential hot water boiler was used as the test equipment. The boiler is rated at 30 kW heat capacity and is equipped with a high efficiency oil burner. The unit is part of the side-by-side test rig, specifically designed for comparative evaluation of fuels and combustion equipment. The test rig is located inside a constant temperature room that maintains test conditions at selected temperatures. The water circulation system and pneumatic control valves were operated using computer-controlled data acquisition software to maintain the boiler inlet and outlet water temperatures at 54°C and 83°C, respectively. The laboratory standard continuous emission analyzers installed on the test rig provided the gas phase emission

concentrations of O₂, CO₂, CO, NO_x and SO₂ concentrations in the stack gas. The operation of the entire test facility is automatically controlled by a dedicated computer system.

PM_{2.5} emissions from the fuels are measured using a source dilution sampler developed at CETC. The fine PM measurement system and the method protocol that provides detailed PM size and emission characteristics have been previously reported (10-14). The sampling procedure that involves sample dilution and cooling provides PM_{2.5}, PM₁₀ and total particulate matter that are formed under ambient simulating or near-atmospheric conditions. The three particulate fractions were collected simultaneously on the dilution sampler using different size selective cyclone inlets. Particulate samples are later analyzed in an ambient-comparable manner for mass, size distribution, carbon, trace element concentrations and soluble sulphates. Briefly, particle size distribution was examined by transition electron microscopy (TEM); trace elements were determined by energy dispersive X-ray fluorescence (XRF); organic and elemental carbon contents by thermal-optical reflectance procedure and particle bound acidic species such as sulphites, sulphates, nitrates and hydrogen ions by ion chromatography (IC). Mass determination of all PM fractions was carried out by gravimetry using a microbalance placed inside a humidity-controlled chamber maintained at 40% relative humidity.

Experimental Procedures

The test boiler operation was optimized using a reference No. 2 heating oil. For this short-term evaluation, accelerated laboratory simulations were used to obtain the experimental results in a short time frame. The combustion test procedure for each experimental setting included two specific burner operation patterns, a short cycle emission monitoring run and one particulate sampling run during which the boiler is operated to be continuously running with no on/off cycles. The short cycle test starts from a cold temperature ignition under a set test room temperature for a 1 hour steady state burner “on” mode, to be followed by three 10 min “on” / 10 min “off” cyclic operation. The fine PM measurement procedure usually requires 6-8 hours of continuous burner “on” operation, depending on the PM emission rate of the fuel. The selected boiler operation conditions include the burner setting of trace smoke, test room temperature of 17-18°C and stack exhaust draft of 0.05 inches of water. For the cold temperature performance of biofuel blend, the temperature of the test room was set at 17°C, 10°C, 5°C and 0°C. These nominal temperature settings were selected to simulate some of the possible average residential boiler room and various fuel tank temperature conditions, including outdoor tanks in Canada, although it is difficult to imitate all varying field environments. Previous experiments have shown that No. 2 fuel is capable of providing normal combustion performance inside the test room set at -10°C. During this brief study only one test temperature of 17°C was selected for the No. 2 fuel combustion experiments. For each temperature setting, the test room and the fuel drum, stored inside the room, were cooled overnight with their temperatures monitored using K type thermocouples. A thermocouple was also installed on the burner oil line, just behind the nozzle to measure the oil temperature at discharge. Similarly, a thermocouple was inserted into the combustion chamber to measure the flame zone temperature. It should be noted that no modifications to the burner or the boiler were made for firing the unit with the B-20 biofuel blend.

RESULTS AND DISCUSSIONS

Cold Temperature Performance

Similar to the reported findings by other researchers, the laboratory observations during this study showed acceptable combustion performance of B-20 biofuel blend on a high efficiency oil burner at normal operating temperatures of 15-18°C. There were no apparent difficulties in burner ignition at cold start, during transient on/off periods and for flame sustenance of up to 10 hours of continuous operation. No noticeable noise louder than normal boiler operation occurred. However, as the test temperature was lowered gradually, a noticeable increase in cold start CO emissions resulted as shown in Figure 1. That indicates a poorer than normal ignition performance of the fuel as evidenced by the increased emissions of incomplete combustion products. However, the burner operation continued with no interruption or failure for an additional two hours, at which time the experiment was terminated. Based on previous research data at CETC, high emissions of CO, hydrocarbons and smoke number indicate increased soot or particulate emissions. Under such conditions soot could accumulate on burner and heat exchanger components as well as in the venting system. Preliminary results suggest that the long-term use of B-20 biofuel blend at temperatures lower than 10°C would have undesirable effects on these components that could reduce appliance efficiency and under extreme cases could create unsafe operating conditions, such as, the oil nozzle blockage and spillage of exhaust emissions. While this study provides useful vital information, field tests over several heating seasons are required to make accurate conclusions on the long-term implications of using these fuel blends.

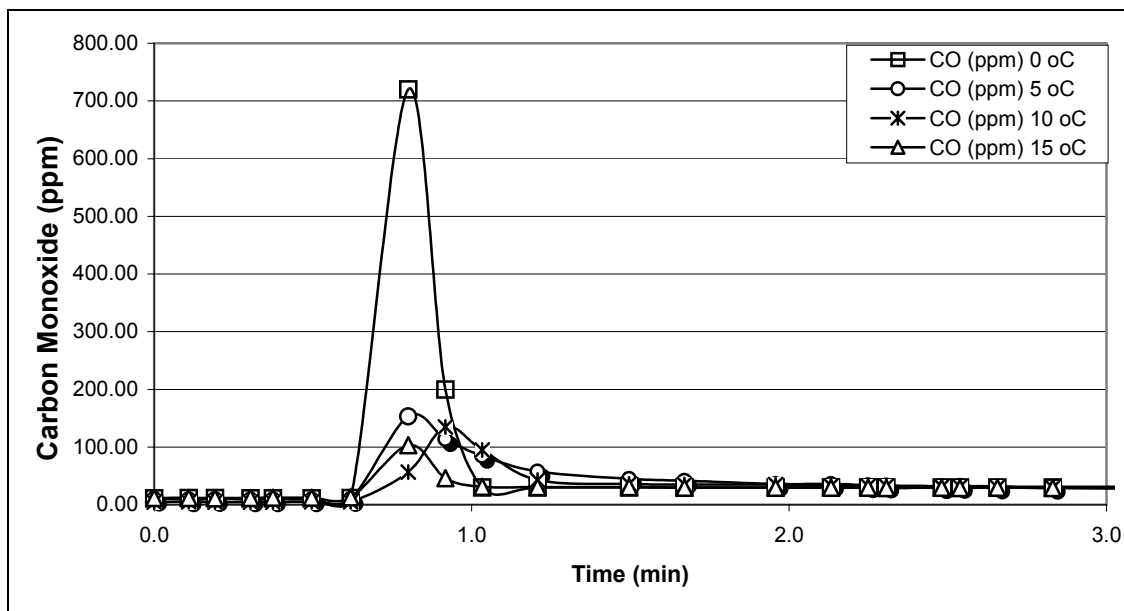


Figure 1: Cold start carbon monoxide emissions from B-20 Bio fuel mixture

Emission Performance

Gaseous emissions

Gas phase emissions of the stack gas emitted from the combustion of test fuels are shown in Table 2. Results of the multiple experiments are given for the B-20 blend only, although, a similar number of experiments were conducted for No. 2 fuel. Each data set represents the averaged steady state emissions over PM sampling tests described above. The averaged data clearly shows a 19.7 ± 2.5 % reduction of SO_2 in the stack emissions of B-20, whereas the other gases, including NO_x are similar for both fuels. Although nitrogen oxides appear to be slightly higher for the B-20 fuel the results are not considered statistically significant. However, according to the analytical data for the fuels reported in Table 1 that show similar reductions by about 21% in both sulfur and nitrogen contents for the biofuel, one would expect a similar reduction in the two emission data. Emission results in Table 2 were reviewed after normalizing them to 3% oxygen. A similar reduction in SO_2 reduction and comparable NO_x concentrations were noted. The data were however excluded in view of the presence of additional oxygen in the stack gas that could be associated with oxygen in the original biofuel.

A previous study at the Brookhaven National Laboratory on B-20 biodiesel showed noticeable reductions in both SO_2 and NO_x (3). An additional experiment was therefore specifically conducted where an instant fuel switch from No. 2 oil to B-20 blend was done during an experiment without interrupting the boiler operation. Figure 2 shows the recorded emission profiles of SO_2 and NO_x for both fuels. This supports the observation noted during individual runs performed on different days. The disagreement between these NO_x values and the mechanisms involved in NO_x formation in the presence of biomass-derived products is not well understood at present. While this warrants further investigations, the observed reduction in SO_2 is an attractive feature, given the well documented impacts of sulfur emissions on the combustion appliance integrity, the environment and human health. Moreover, the reduction in green house gases associated with the reduced use of petroleum fuels could also be achieved by utilizing renewable biofuels.

Table 2: Steady state gaseous emissions from B-20 biofuel blend.

		1	2	3	4	5	6	Average B-20	Average No.2 Fuel
Test Room Temp.	°C	16.59	16.9	16.7	17.7	18	18.0	17.3	17.7
Stack Temp.	°C	259	256	256	252	253	254	255	253
Stack Emissions									
Oxygen	%	4.4	5.0	4.6	4.8	4.9	4.6	4.7	4.6
Carbon Dioxide	%	13.2	12.8	13.0	12.9	12.7	12.9	12.9	12.9
Carbon Monoxide	ppm	39	28	35	31	28	30	32	30
Sulphur Dioxide	ppm	79	76	78	75	78	78	77	96
Nitrogen Oxides	ppm	110	109	112	106	109	110	109	104

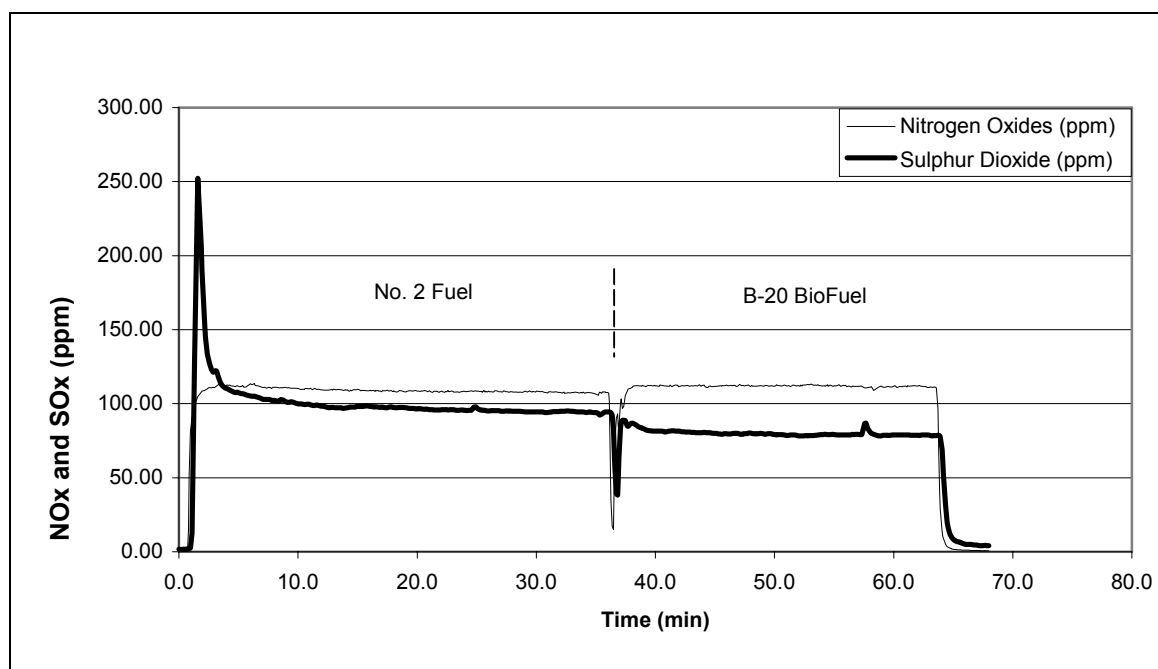


Figure 2: Sulphur and Nitrogen emission trends for No.2 fuel and B-20 biofuel

Particulate emissions

Table 3 gives PM mass emission results including the fine fractions of $PM_{2.5}$, PM_{10} and total PM for both fuels. Results are expressed in terms of filterable PM mass in mg/m^3 dry flue gas at standard temperature and pressure. Each sampling run collects one filter sample each for $PM_{2.5}$ and PM_{10} fractions and two for the total PM fraction. Total mass emission result therefore represents the average result of duplicate runs. The results for all independent runs are given along with the calculated relative standard deviations to demonstrate the data reproducibility. The data show the apparent similarity of the mass concentrations for all PM fractions for a test fuel. This suggests that all particulates emitted from both fuels when fired in a residential boiler fall in the $PM_{2.5}$ fraction. Previous research at CETC on low sulphur diesel and No. 2 type distillate fuels have shown similar results, which were supported by size analysis of particles using scanning electron microscopy (14). Similar studies done for the transportation and mining engines also reported that diesel fuels normally generate very small particles less than $1\ \mu m$ in diameter, known as ultra-fine PM. While this study does not specifically focus on the size characteristics of particles produced by the combustion of biofuel blends new information became available on their quantities and types. The data in Table 3 shows that the PM emission concentrations from B-20 biofuel are lower than those from No. 2 oil by approximately $15.7 \pm 7.5\%$. It should be noted that the results are preliminary since only a limited number of replicate runs were completed in this brief study. However, this is a significant benefit that can be realized from the application of biofuel blends in stationary combustion systems.

Table 3: Comparison of fine particulate emissions from No. 2 oil and B-20 biofuel blend

Fuel	Run	PM _{2.5} mg/m ³	PM ₁₀ mg/m ³	PM _{Total} mg/m ³
B-20 Bio fuel	1	12.9	12.7	12.3
	2	14.0	11.8	13.0
	3	12.7	11.8	12.0
	AVG	13.2	12.1	12.4
	RSD (%)	5.4	4.1	4.3
No. 2	1	15.7	15.5	15.2
	2	13.9	14.0	14.7
	AVG	14.8	14.7	14.9
	RSD (%)	8.5	7.1	2.5

PM chemical composition. A better understanding of the chemical constituents of ambient particles is fundamental in bridging the knowledge gap between the air quality and its health effects. Ambient fine particles are generally made up of numerous species depending on the sampling location and the quantity and quality of emissions from contributing sources. These include acidic species such as sulphates and nitrates that exist as ammonium salts, carbon species, water, trace elements mainly in the form of oxides, earth crustal matter and other airborne fragments of natural and anthropogenic origins. On the other hand, combustion source PM is mainly composed of carbon species, condensed acidic species, water and trace elements. Sulphates and nitrates in PM are formed during the secondary PM formation process when primary PM such as SO_x and NO_x undergo a gas-to-particle transformation process. Sulphuric and hydrochloric acids also condense on PM surfaces and are usually detected as soluble sulphate and nitrate ions when the samples are dissolved in water. Two types of carbons are produced during fossil fuel combustion, organic carbons (OC) and elemental or graphitic carbons (EC), the latter being a key contributor to the atmospheric visibility degradation. Organic carbons are associated with numerous and complex organic species, some of which are known air toxic compounds. The acids and toxic trace elements found in ambient fine PM have been linked to a few known illnesses in humans and research animals. CETC has incorporated a comprehensive analysis protocol for quantifying these important chemical constituents of particulate emissions and this protocol was applied in this study to examine the changes in PM characteristics of heating fuel when blended with biofuels.

Preliminary results for the B-20 blend of soybean methyl ester are reported in Table 4, along with those of No. 2 fuel oil. For each PM fraction, averaged concentrations of the key components are reported in terms of mass in mg/m³ dry flue gas at standard temperature and pressure. A much higher concentrations of sulphates than those of trace elements, expressed as metal oxides, and the carbons are noted. This indicates a clean combustion process for both fuels and the dominant nature of sulphates in particulate materials. Only minute quantities of trace elements are normally generated during combustion of distillate fuels since they contain only minute amounts of inorganic trace elements in the fuel matrix. Similarly, a trace smoke emission setting provided by the high efficiency burner is reflected by the low concentrations of PM carbon contents.

It should be noted that trace element data by XRF analysis has associated instrumental errors although not reported here. Similarly the OC/EC analysis technique is method dependent and the results could be slightly different if the analysis was done using a different technique. However, these limitations are well recognized by the scientists in air pollution research and the current data was carefully interpreted with this knowledge.

Particle bound sulphate content found in biofuel emissions are lower than that of No. 2 oil emissions. A reduction of 14.1±6.1 % in sulphate content from biofuel was noted when

compared with those from No. 2 oil. These appear to be in good agreement with the observed 19.7 ± 2.5 % reduction in stack SO_2 emissions for the biofuel blend. This significant reduction in PM sulphate has positive implications regarding appliance integrity, environmental impacts and more importantly, health effects on local population.

Table 4: Chemical constituents of particulate emissions from No. 2 oil and biofuel blend

Fuel	Constituents	PM _{2.5} mg/m ³	PM ₁₀ mg/m ³	PM _{Total} mg/m ³
B-20	Metal as oxides	0.11	na	0.26
	Organic carbon	0.64	0.62	0.71
	Elemental carbon	0.04	0.05	0.05
	Sulphates	5.9	5.5	5.6
	Water associated with sulphate	6.5	6.1	6.2
	Total mass by composition analysis	13.2	12.3	12.8
	Total mass by gravimetry	13.2	12.1	12.4
No. 2	Metal as oxides	0.18	na	0.19
	Organic carbon	0.63	0.57	0.61
	Elemental carbon	0.21	0.23	0.21
	Sulphates	6.7	6.3	6.6
	Water associated with sulphate	7.4	6.9	7.3
	Total mass by composition analysis	15.1	14	14.9
	Total mass by gravimetry	14.8	14.7	14.9

Note: Mass balances are average values for multiple runs

CONCLUSIONS

This brief study covered short-term laboratory investigations of a 20% biofuel blend. The conclusions derived from this study are based on initial results and are only intended as a research update. Additional experiments are underway to verify these results and until such time, this information should only be considered preliminary.

The experiments conducted in this investigation were carefully and systematically controlled to provide reproducible results. Advanced equipment and novel emission measurement protocols provided new scientific information that can be used for important health effect studies of oil combustion generated pollutants.

A soybean methyl ester blended into No. 2 fuel oil by 20% by volume showed normal combustion performance on a residential oil-fired boiler, comparable to that of No. 2 fuels. No modifications to the procedure or the combustion equipment were required. However, transient emissions of incomplete combustion products, CO and soot, increased at cold start when the test room temperature was lower than 15°C. This indicates potential soot accumulation on burner and appliance components that, if operated over several heating seasons, could lead to reduced thermal efficiency and unsafe operating conditions. Operating temperatures lower than 10°C is not recommended for long-term use of this fuel blend without additional information on the cold temperature performance problems.

The combustion of B-20 biofuel blend exhibited similar gaseous emissions to those of No. 2 fuel oil, with the exception of SO_2 , which was 19.7 ± 2.5 % lower. Nitrogen oxides from the biofuel are similar to those of No. 2 oil. PM emission concentrations from biofuel are lower than those from No. 2 oil by 15.7 ± 7.5 %. Significant reductions in particle bound sulphate were also

noted, by 14.1 ± 6.1 %, when compared with those from No. 2 oil. These indicate several potential benefits of using the biofuel blend in residential space and water heating and in industrial processes.

Long-term studies need to be conducted to determine appliance performance and unit component integrity over several seasons. The current field trials being demonstrated by Brookhaven National Laboratory would provide useful information in this area. Research on the effects of biofuel matrix on the integrity of certain combustion equipment components have been initiated by the oil heating industry although it is not as widespread as the studies on transportation engine components. The long-term chemical and thermal stability of the biofuel blends need to be investigated as well.

Future Research in Canada will focus additional work on cold temperature performance of the blends and necessary modifications to allow for the safe and efficient use of these blends in cold climates. More laboratory experiments are considered necessary to confirm the preliminary data. Additional research on fine PM emissions from different biofuel blending stocks is being planned in cooperation with Canadian fuel producers.

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Paper No. 09-03
Combustion Testing of a Bio-diesel Fuel Oil Blends in
Residential Oil Burning Equipment

John Batey, PE
Energy Research Center, Inc.
35 Fawn Rd.
Easton, CT 06612
(203) 459-0353
E-mail: erc@optonline.net

Funded by:
National Oilheat Research Alliance
Massachusetts Oilheat Council

With the cooperation of:
New England Fuel Institute
Advanced Fuel Solutions, Inc.

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By: John E. Batey, PE, Energy Research Center, Inc.

Acknowledgements

The work summarized in this report is a collaborative effort between the National Oilheat Research Alliance (NORA), the Massachusetts Oilheat Council (MOC), the New England Fuel Institute (NEFI), Advanced Fuel Solutions, Inc., the Energy Research Center, Inc., the service managers who participated in this oilheat equipment testing program, and others who supplied valuable input and guidance.

NORA supplied the funding that was required to support the engineering and technical services, the test equipment, and other supplies that were required for this project.

Michael Ferrante, President of the Massachusetts Oilheat Council, was responsible for conceiving of the project, procuring the funding that was needed, and supplying overall project direction and management.

Jack Sullivan of the New England Fuel Institute supplied the facilities and support personnel for conducting the tests, and Michael Markarian provided on-site management of the project that included testing a range of oil fired boilers and furnaces that are included in the NEFI training facility.

Paul Nazzaro of Advanced Fuel Solutions supplied the Bio-diesel test fuels and assistance with project planning and review of test results.

The work of Tony Ruffo and Dave Bessette, two highly experienced oil heat service managers, is gratefully acknowledged. They conducted the combustion testing of all the oil heat equipment that was included in this project, and supplied valuable insight into the operation of oil heat systems and the potential advantages offered by bio-diesel fuel blends. They were critical to the successful and timely completion of this project.

We thankfully acknowledge the discussions and technical input, including review of data and interim and draft reports, by Ray Albrecht of the New York State Energy Research and Development Authority, and Tom Butcher, Roger McDonald, and CR Krishna who are research engineers at Brookhaven National Laboratory.

1. Executive Summary

Biodiesel fuel blends have been shown to lower air emissions in residential and small commercial oil heating equipment. The purpose of this study is to evaluate the combustion performance of a **20% soy-based biodiesel fuel blended with a low sulfur (0.05%) highway diesel** compared to conventional home heating oil. Tests were conducted at the New England Fuel Institute Training facility using a range of conventional oil powered boilers and furnaces over a range of fuel firing rates and excess combustion air settings.

Key observations and findings of these combustion tests include:

- **Nitrogen Oxide** emissions are frequently reduced by about 20% by using the biodiesel/low sulfur blend.
- **Combustion stability** with the biodiesel blend is very good as indicated by low levels of carbon monoxide that are similar to the conventional fuel oil.
- **Sulfur Oxide** emissions are reduced by 83 percent by using the biodiesel fuel
- **Smoke numbers** are lower with the biodiesel blend than the home heating oil when the same burner air setting is used.
- **Fuel oil and combustion odors** are improved by using the biodiesel /low sulfur oil blend compared to home heating oil based on these preliminary tests.

This combustion test project demonstrated that very good combustion performance is produced by the biodiesel fuel blend in the conventional residential oil heating equipment that was tested. No significant changes in carbon monoxide levels (incomplete combustion) were observed as a function of excess combustion air. Substantial reductions in air emissions with the biodiesel blend were observed, producing much lower environmental impacts than conventional home heating oil. This includes reductions in sulfur oxides (83%), nitrogen oxide (20%), carbon dioxide (20%), and particulate matter. Preliminary analyses indicate that the 20% soy-based biodiesel/low sulfur diesel blend has an environmental cost that is better than natural gas when gas leakage during transmission, storage, and distribution are included. This helps to transform home heating oil into a premium fuel with very favorable environmental impacts.

Other benefits include improved odor characteristics, and domestic production of part of the fuel supply from soy bean crops.

The next steps needed to further evaluate biodiesel fuels include:

1. Combustion testing for a range of biodiesel blends to optimize performance and costs
2. Tests of cold-flow characteristics
3. Test of biodiesel fuels with ultra-low (0.0015 %) fuel oil
4. Long-term tests of boiler fouling rates with biodiesel fuels
5. Field tests and demonstrations of biodiesel blends.

2.0 Introduction

Bio-diesel fuels and blends of bio-diesel and distillate heating oils have been shown to reduce air emissions and offer other advantages compared to conventional heating oil. Recent combustion tests by Brookhaven National Laboratory indicate that blends of heating oil and bio-diesel fuel can lower nitrogen oxide emissions from residential oil burners by 10 percent to 20 percent when compared to conventional distillate fuel oil. In addition, sulfur oxides and greenhouse gas emissions are also substantially lowered. Tests completed prior to this study often have been limited to a single burner-boiler or burner-furnace.

The purpose of this test project was to perform combustion tests on biodiesel and normal fuel oils in a range of residential oil boilers, furnaces, and combustion chamber configurations, and to analyze combustion performance for various operating conditions. The objective was to identify

potential benefits in combustion performance and lowered air pollutant emissions, while noting any combustion problems caused by using biodiesel fuel oil. The primary focus of this initial study was on the combustion performance of biodiesel fuels compared to conventional fuel oil.

All combustion tests were performed at the NEFI training center in Watertown Massachusetts. The NEFI facility has a wide range of burners, boilers, and furnaces that are used for training oilheat service technicians. Most of the burner-boiler and burner-furnace units that were selected were evaluated at 3 or more firing rates, and at 3 or 4 excess combustion air settings to evaluate a range of operations. Combustion measurements that were completed include: flue gas smoke, carbon dioxide, oxygen, carbon monoxide, draft, and nitrogen oxide emissions.

Attachment A is a table that summarizes the tests that were completed as part of this project.

3. Methodology

This combustion test project was designed to compare the performance and emissions of a 20% biodiesel fuel blend in low sulfur diesel fuel with conventional heating oil in residential boilers and furnaces. Heating equipment to be tested included a range of oil burners, furnace, and boilers including older and new equipment in a wide range of designs.

The following equipment was selected for testing.

Unit #1:	Small-commercial Steam Boiler, steel construction, Flame Retention Oil Burner, 2.5 gallon per hour fuel nozzle
Unit #8:	Older Residential Hot Water Boiler, cast-iron construction Flame Retention Oil Burner, 0.75 gallon per hour fuel nozzle
Unit #10:	Compact, Residential Hot Water Boiler, steel construction Flame Retention Oil Burner, 0.75 gallon per hour fuel nozzle
Unit #13:	Older Residential Warm Air Furnace, steel construction Flame Retention Oil Burner, 0.65 gallon per hour fuel nozzle
Unit #22:	Residential Hot Water Boiler, cast-iron construction Flame Retention Oil Burner, 0.75 gallon per hour fuel nozzle
Unit #23:	Residential Hot Water Boiler, cast-iron construction Flame Retention Oil Burner, 0.75 gallon per hour fuel nozzle

Test Instruments

Test instruments for performing combustion testing and flue gas analysis that were used for this project included the following.

Testo 300 M - Commercial & Industrial Combustion Analyzer with printer that measures: Oxygen (O₂), Carbon Monoxide (CO), Nitric Oxide (NO), Nitrogen Oxides (NO_x), Flue temperature, and draft.

Testo 325-i - individual gas analyzer for measuring sulfur dioxide (SO₂) content of the flue gases.

Fuels tested

The biodiesel fuel that was evaluated was a blend of 20% soy-based biodiesel combined with 80% low sulfur highway diesel, which is referred to as the biodiesel or biodiesel blend in this report. The second fuel was conventional number 2 distillate home heating oil that is used at the NEFI training facility. A limited number of tests were conducted on a third fuel. This is a 20% soy-based biodiesel fuel combined with 80% number 2 home heating oil that is available at the NEFI facility.

4. Test Results and Analysis

Attachment A is a Table which summarizes key information about the various boilers and furnaces that were tested using the biodiesel- fuel oil blends and conventional home heating oil. Example of the detailed test results for the heating equipment included in this project are contained in **Attachment B**. Combustion tests that were completed included measurement of the following flue gas constituents: Nitric Oxide (NO) and Total Nitrogen Oxides (NO_x), Sulfur Dioxide, Carbon Monoxide, Smoke Number, and Flue Gas Temperature

Each of these combustion test parameters will be discussed for all the equipment that was tested, and engineering analyses will be presented and discussed. Specific references will be made to the test data contained in Attachment B.

a. Reduced Nitrogen Oxide Emissions with Biodiesel Blends

A significant reduction in Nitrogen Oxide (NO_x) emissions was observed in many cases when the conventional home heating oil was replaced with the low sulfur highway diesel blended with 20% biodiesel fuel. Typical reductions in NO emissions of about 20 parts per million or about 20% were observed. A brief discussion follows for an example warm air furnace that was tested. **Attachment B-1** shows Nitric Oxide (NO) emissions as a function of excess air setting for test unit #13, fired at 0.75 gallons per hour, and corrected for 3 percent oxygen in the flue gas. For this conventional warm air furnace, the Nitric Oxide (NO) emissions decrease by approximately 20 parts per million when the conventional heating oil is replaced by the biodiesel/highway diesel blend. This reduction was observed over the entire range of burner excess air settings that were evaluated. For this furnace, the NO levels increase to a maximum value when the flue gas oxygen level reaches about 5 percent. At this air setting, the low sulfur diesel/ bio-diesel blend produces about 95 parts per million (ppm) of NO, while the conventional home heating oil produces about 115 ppm. This is a significant reduction in emissions. When the furnace was fired at 0.65 gallons per hour, a similar reduction in NO emissions was measured for the biodiesel blend. However, when the same furnace was fired at 0.5 gph, the observed Nitric Oxide reductions were slightly lower at about 15 ppm.

b. Carbon Monoxide Emissions with Biodiesel Blends

In general, similar carbon monoxide (CO) emissions were produced by the biodiesel/low sulfur diesel blend and the conventional home heating oil. The total emission rates and changes in CO

emissions as a function of flue oxygen content were also similar for the two fuels that were tested. A brief discussion follows for one of the warm air furnaces that were tested. Carbon Monoxide (CO) is an important measure because it indicates how completely the fuel is burned. Elevated CO levels indicate incomplete combustion. **Attachments B-2 and B-3** show carbon Monoxide emissions for the typical heating units that was part of the test project.

Attachment B-2 shows the test results for unit #13 - a warm air furnace with a firing rate of 0.75 gallons per hour. The Carbon Monoxide emission profiles are virtually the same for both fuels for the entire range of flue oxygen percentages that were tested. The minimum Carbon Monoxide levels are the same and occur for burner air settings that are between 4% and 9% flue oxygen. The CO levels begin to rise for both fuels when the flue oxygen percent falls below 4 percent. This suggests that combustion stability is similar for the biodiesel/low sulfur blend and the standard home heating oil.

Attachment B-3 for test unit #10 fired at 0.65, 0.80, and 0.92 gph with the biodiesel blend only. This shows the entire range of CO emissions for burner air settings that vary from 3 percent to 12 percent oxygen in the flue gas. This is the classic “U-shaped” carbon monoxide curve that shows a large increase on the left side of the plot from incomplete combustion as the excess air is reduced. On the right side of the curve, excess air levels increase and the flame temperature drops causing the chemical reaction rates to decrease. This also causes elevated carbon monoxide production rates as the burner excess air is increased and flue gas oxygen content approaches and exceeds 12 percent. This is similar to the CO-versus -excess air curves for conventional #2 heating oil.

c. Other Test Observations and Discussions

The Sulfur Dioxide (SO₂) content of the flue gas was measured as part of the emissions testing. The SO₂ emissions are directly related to the sulfur content of the fuel oil or fuel oil blend. Tests on heating unit #10 produced sulfur dioxide emissions in the flue gas that averaged 90 parts per million when tested with the conventional home heating oil after it is corrected for 3 percent excess air. When the same boiler was operated with the low sulfur diesel and biodiesel oil blend, the SO₂ emissions fell to 15 parts per million. Based on these measured sulfur dioxide levels, and using information published by Industrial Combustion, the fuel sulfur contents for the two heating fuels were calculated to be 0.17 percent by weight for the conventional home heating oil, and 0.028 percent for the biodiesel low sulfur diesel blend.

The flue gas temperatures were measured during the combustion tests, and no significant differences were observed for the two fuels that were tested.

One important observation during testing was the change in smoke number for the two fuels that may exist when the burner air setting is not changed. **Attachment B-4** shows Smoke Number versus burner Air Shutter Setting for test unit #22. When the burner is set for a zero smoke with the biodiesel fuel, the smoke increased to a number 3 when the standard home heating oil was used without readjusting the burner air setting. *This means that burner adjustment should be checked whenever a burner is switched from a biodiesel blend to conventional heating oil.*

One additional observation during combustion testing was the improvement in fuel and combustion odors offered by the biodiesel/low sulfur oil blend when compared to conventional home heating oil. The people working on this test project felt that the biodiesel fuel blend has a less objectionable odor in its unburned form. In addition, at times when the combustion gas escaped from the boiler or furnace being tested, the biodiesel fuel blend had a more favorable odor. In fact, the odor was found to be much less intense and more pleasant smelling. Aroma testing was not a part of this test project. This is an area that needs further evaluation and quantitative testing. Part of the improvement in fuel and combustion product odor is most likely produced by using the low sulfur (0.05%) diesel fuel.

5. Conclusions and Recommendations

This preliminary testing program has demonstrated that the biodiesel blend consisting of 20 percent soy-based biodiesel and 80 percent low sulfur highway diesel fuel produces improved emissions and very good overall combustion characteristics. Air emissions of several key pollutants are lowered substantially. In addition, good combustion performance was observed for the biodiesel blend in a range of conventional oil heating boilers and furnaces.

a. Air Emissions Improvements

Nitrogen Oxide emissions were lowered by approximately 20 percent for many of the conventional home heating units that were tested when compared to emissions from conventional home heating oil. This is a substantial reduction that moves home heating oil into a very elite group of low emitting fuels. Part of the reduction is due to using low sulfur highway diesel, and part is due to the biodiesel fuel. The biodiesel / low sulfur diesel blend substantially reduces nitrogen oxide emissions from residential oil burning equipment. In fact, this reduction is on the same order as the levels mandated in the mid-1990s by state departments of environmental protection of 25 to 30 percent for commercial and industrial boilers.

Sulfur Oxides emissions are reduced by as much as 80 percent or more which is another important benefit produced by the biodiesel fuel blended with low sulfur highway diesel. The sulfur in the fuel is converted directly to Sulfur Dioxide (SO₂) when it burns which is a primary air pollutant controlled by the USEPA that contributes to acid rain. Conventional home heating oil has historically contained on the order of 0.25 percent sulfur by weight. By using the highway diesel fuel at 0.05 percent sulfur, sulfur oxide emissions can be reduced by 80 percent. The soy-based biodiesel contains very low sulfur, which can lower sulfur oxide emissions even more. Sulfur Dioxide (SO₂) emissions were reduced from approximately 90 ppm for the conventional home heating oil to 15 ppm for the biodiesel /low sulfur blend during this test project. This is an **83 percent reduction** in sulfur oxide emissions which is expected based on typical fuel sulfur contents.

One other important environmental benefit is the reduction in carbon dioxide emissions which is a greenhouse gas that contributes to global warming. The biodiesel fuel is regenerated by growing more soy plants. This process absorbs carbon dioxide from the air. The net effect of using a biomass fuel is a reduction in carbon dioxide emissions proportional to the percentage of biodiesel that is consumed. Therefore, using a 20 percent biodiesel fuel blend can lower

effective carbon dioxide emissions by 20 percent. This substantially reduces the difference in greenhouse gas emissions between home heating oil and natural gas.

These reductions in nitrogen oxide, sulfur oxide, and greenhouse gas (carbon dioxide) emissions by using the biodiesel fuel blend produce very significant environmental benefits for home heating oil. It virtually eliminates any remaining environmental advantage that can be claimed by natural gas powered heating equipment. From an environmental perspective, the soy-based biodiesel fuel blended with low sulfur diesel that was tested is a premium fuel that has extremely low air emissions. Preliminary calculations indicate that its environmental impact and cost that may be even lower than natural gas when leakage rates during gas storage, transmission, and distribution are included. This can be verified by further analyses and evaluation of environmental costs for the two fuels using updated environmental cost factors. See **Attachment C** for these preliminary findings.

b. Favorable Combustion Performance and Characteristics with Biodiesel Fuels

The combustion tests completed to date indicate very good combustion performance of the biodiesel / low sulfur fuel blend when used to power residential oil heating equipment. Carbon Monoxide is an indicator of the completeness of combustion and the relative stability of the burner. When the biodiesel blend was used, it produced carbon monoxide emission rates as a function of burner air adjustment that were very similar to conventional home heating oil. The same “U-shaped” curve that is observed for home heating oil was also observed for the biodiesel blend. In several tests, carbon monoxide emissions began to rise slightly sooner than as the burner excess air was lowered. However, in other cases (unit #10, for example) the carbon monoxide levels were much lower for the biodiesel blend than for the conventional heating oil over the entire range of burner air adjustments.

In general, carbon monoxide levels were very similar for the two fuels, and the shape of the CO versus Flue Oxygen Percent (excess combustion air) were very similar. This suggests that the biodiesel blend is compatible with residential oil burning equipment for the range of heating unit tests completed to date.

c. Other Benefits: less odor, home-grown fuel

Reduction of objectionable odors is another potential benefit based on the preliminary qualitative assessments completed as part of this project. All the observers of these tests agreed that the biodiesel /low sulfur diesel blend produce better-smelling combustion products than the conventional home heating oil. Quantitative testing is needed to substantiate and measure this preliminary finding.

Another favorable attribute of the soy-based biodiesel fuel is that it is a home-grown agricultural product that is not dependent on foreign fuel reserves. In this way, the biodiesel fuel blend can help to reduce dependence on foreign sources to a certain degree. It is important to be able to use energy sources from within the US as part of the energy mix. Biodiesel fuel blends may allow this to happen.

Next Steps

This preliminary evaluation of biodiesel fuel blends focused solely on the combustion performance of a single 20 percent biodiesel blend in home heating equipment. Follow-up activities that are recommended include the following.

1. **Evaluate combustion performance and emissions reductions benefits for a range of biodiesel blends and for varying fuel sulfur contents** of the fuel into which the biodiesel product is blended. This is needed to optimize performance improvement for various fuel price increases for biodiesel blends, including potential tax credits and possible emission reduction credits.
2. **Test the cold-flow characteristics of biodiesel fuels and biodiesel fuel blends** for a range of temperatures to simulate the effect of storage in above-ground outdoor fuel storage tanks. Specifically, evaluate pour point, cloud point, and filter plug points to assure compatibility in colder climates.
3. **Test the interactive effect of biodiesel when combined with ultra-low sulfur** (0.0015 percent or 15 ppm sulfur) fuel oil. Some combustion problems have been observed with the ultra-low oil including damage to flame tubes caused by unexpected chemical reactions. The impact of using biodiesel blends with the ultra-low fuel oil needs to be evaluated.
4. **Long-term tests of reductions in boiler and furnace fouling rates** with the biodiesel and low sulfur biodiesel fuel blends needs to be evaluated similar to the work completed at Brookhaven National Laboratory for the low sulfur (0.05%) fuel oil. This is important to fully evaluate potential service cost savings by extending the intervals between vacuum cleanings.
5. **Field Studies of biodiesel blends are needed** to test and demonstrate the advantages of these fuels in actual home heating installations. This is similar to the on-going demonstration of the advantages of low sulfur heating oil by the New York State Energy Research and Development Authority (NYSERDA). This is important for quantifying the benefits and identifying any problems that may arise related to using the biodiesel blends.

Attachment A - Summary of Tests Completed
NORA / MOC Biodiesel Blend Tests At NEFI

REF	Unit NEFI No.	Unit Type	Fuel Nozzle Gph	Pressure psig	Flow Rate gph	Fuels Tested Biodiesel	Fuel Oil
B-1	13	WAF	0.75	100	0.75	20% Bio/LSF	#2 oil
B-2	13	WAF	0.65	100	0.65	20% Bio/LSF	#2 oil
B-3	13	WAF	0.50	100	0.50	20% Bio/LSF	#2 oil
B-4	22	HWB	0.85	100	0.85	20% Bio/LSF	#2 oil
B-5	22	HWB	0.65	100	0.65	20% Bio/LSF	#2 oil
B-6	8	HWB	0.65	100	0.65	20% Bio/LSF	#2 oil
B-7	23	HWB	0.75	100 / 160	0.75 / 0.95	20% Bio/LSF	#2 oil
B-8	10	HWB	0.75	100	0.75	20% Bio/LSF	#2 oil
B-9	10	HWB	0.75	130	0.85	20% Bio/LSF	#2 oil
B-10	10	HWB	0.75	175	0.99	20% Bio/LSF	#2 oil
B-11	10	HWB	0.65	100/150/200	0.65	20% Bio/LSF	#2 oil
B-12	10	HWB	0.50	130	0.58	20% Bio/LSF	#2 oil
B-13	10	HWB	0.50	150	0.62	20% Bio/LSF	#2 oil
B-14	10	HWB	0.50	200	0.70	20% Bio/LSF	#2 oil
B-15	1	StB	2.50	100	2.50	20% Bio/LSF	#2 oil
B-16	1	StB	2.50	150	3.10	20% Bio/LSF	#2 oil
B-17	1	StB	2.50	200	3.50	20% Bio/LSF	#2 oil
B-18	23	HWB	0.75	100	0.75	#2 Oil/LSF	#2 oil
B-19	22	HWB	0.75	100	0.75	#2 Oil/LSF	#2 oil
B-20	13	WAF	0.75	100	0.75	#2 Oil/LSF	#2 oil

NOTES:

WAF: Warm Air Furnace

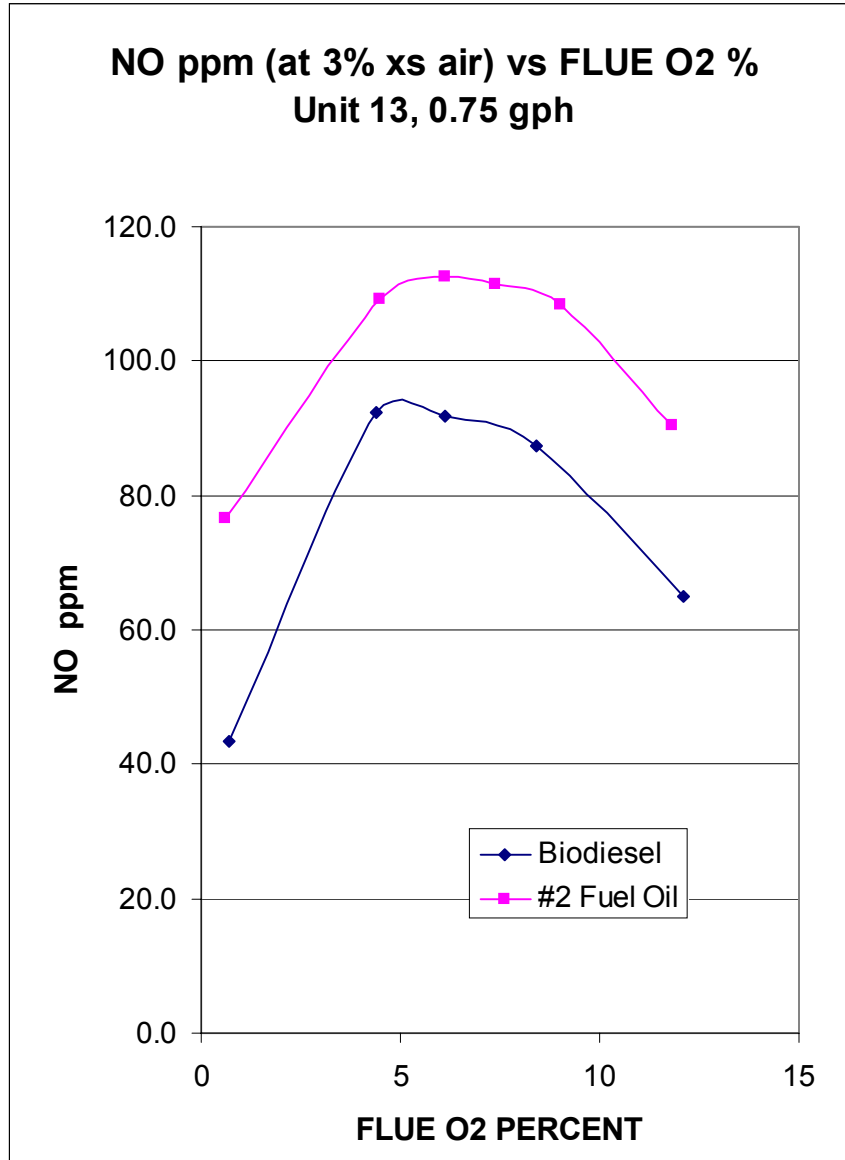
HWB: Hot Water Boiler

StB: Steam Boiler

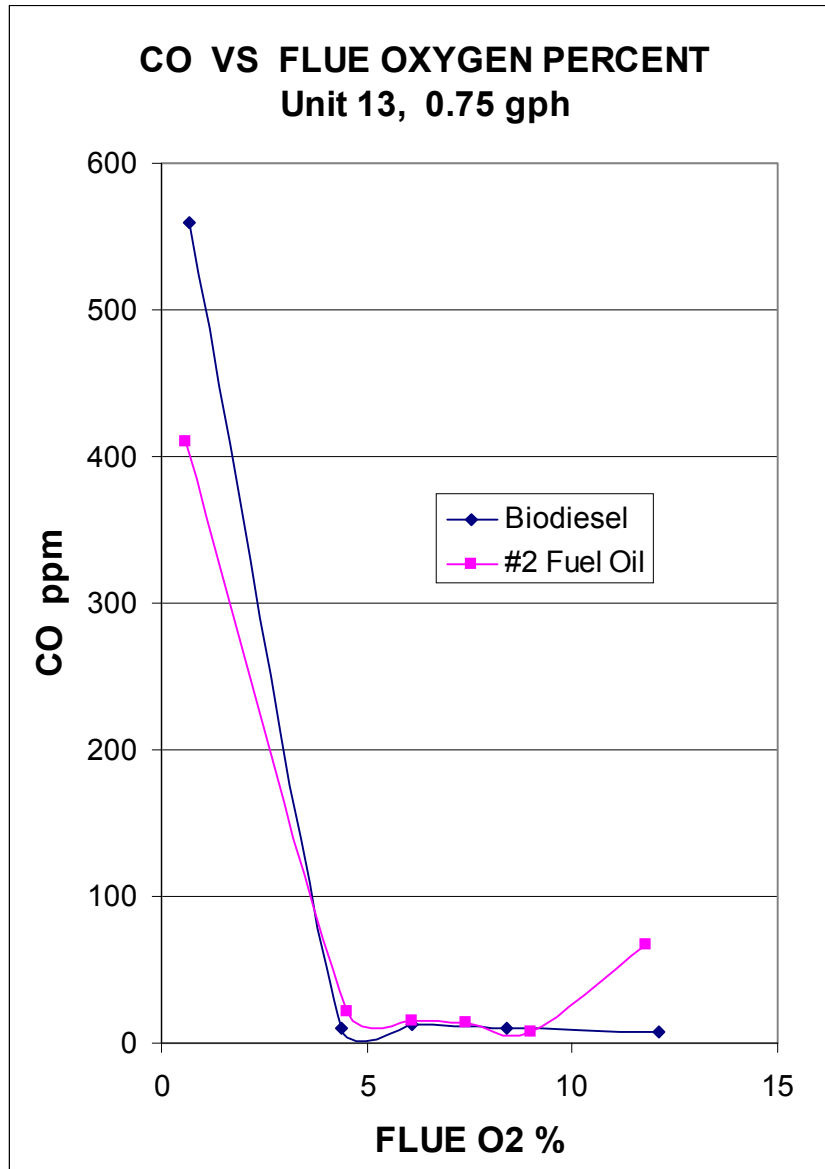
Bio: Soy-based Biodiesel fuel

LSF: low sulfur (0.05%) Home Heating Oil

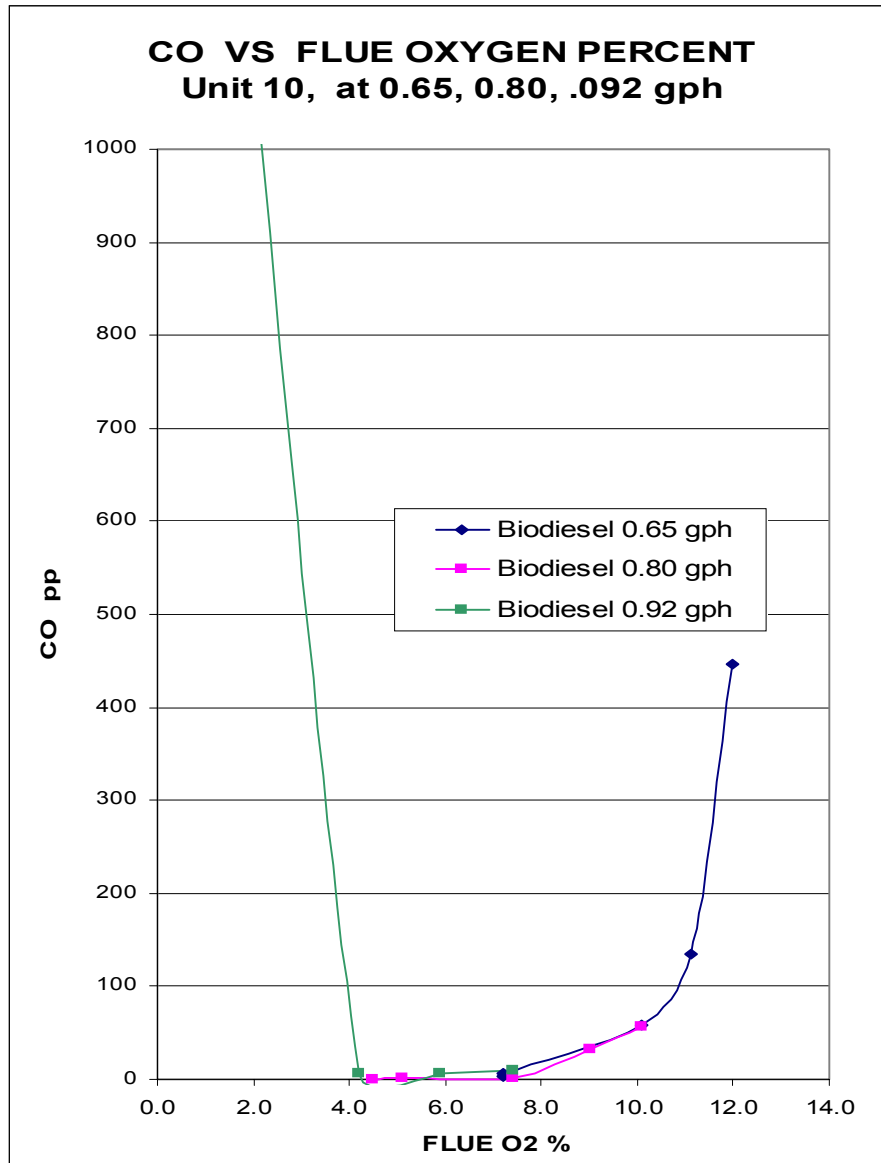
Attachment B-1: Test Unit #13, 0.75 gph



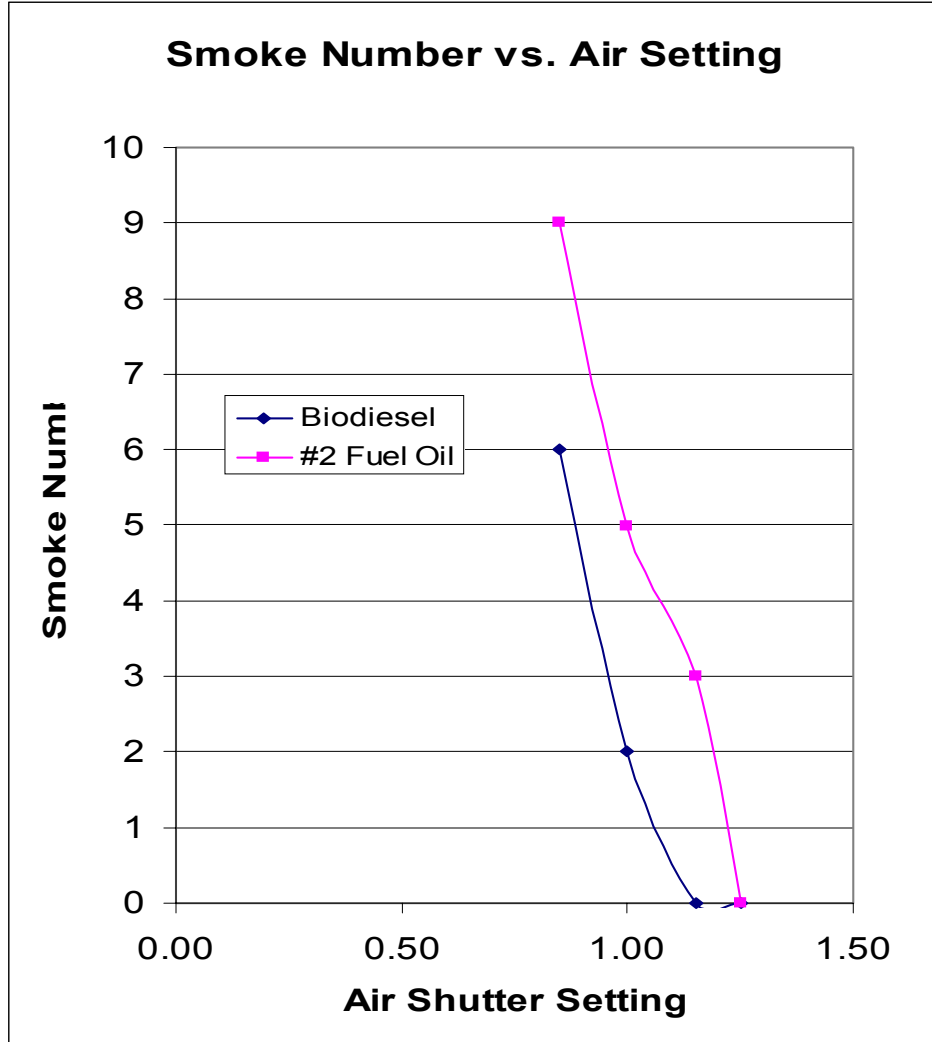
Attachment B-2: Test Unit #13



Attachment B-3: Test Unit #10, 0.65 gph at 100/150/200 psig



Attachment B-4: Test Unit #22, 0.85 gph



Attachment C

